

MONTHLY MAPS OF SEA LEVEL ANOMALIES IN THE PACIFIC 1975-1981

KLAUS WYRTKI and SHIKIKO NAKAHARA

AUGUST 1984

Prepared for
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
under JIMAR Cooperative Agreement NA80RAH00002
as part of the
IGOSS SEA LEVEL PILOT PROJECT

HAWAII INSTITUTE OF GEOPHYSICS
UNIVERSITY OF HAWAII
HONOLULU, HAWAII 96822



MONTHLY MAPS OF SEA LEVEL ANOMALIES IN THE PACIFIC

1975-1981

Klaus Wyrtki and Shikiko Nakahara

August 1984

Prepared for
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
under JIMAR Cooperative Agreement NA80RAH00002
as part of the
IGOSS SEA LEVEL PILOT PROJECT



Dennis Wilson Moore
Director
Joint Institute of Marine
and Atmospheric Research



Charles E. Helsley
Director
Hawaii Institute of Geophysics

ABSTRACT

Sea level data obtained on islands in the tropical and subtropical Pacific Ocean are used to compile maps of the sea level anomaly for each month of the period January 1975 to December 1981. The maps reveal the large horizontal coherence of sea level anomalies with space scales of several thousand kilometers. Coherence scales are larger in the east-west than in the north-south direction. The anomalies are also coherent over many months indicating a dominance of low-frequency variations.

CONTENTS

	<u>Page</u>
ABSTRACT.	iii
LIST OF TABLES	vi
LIST OF FIGURES	vi
HISTORY AND BACKGROUND	1
DATA PROCESSING	2
DISCUSSION	5
ACKNOWLEDGMENTS	6
REFERENCES	7
MONTHLY MAPS OF SEA LEVEL ANOMALIES FOR 1975-1981 (unpaged)	9

TABLES

Table

Page

1. Location of sea level stations in the Pacific. 3

FIGURES

Figure

1. List of sea level stations in the Pacific. 4

HISTORY AND BACKGROUND

The installation of an island-based network of sea level gauges in the Pacific Ocean from 1974 through 1975 (Wyrтки, 1979a) has resulted in a variety of scientific discoveries and stirred considerable scientific interest in the use of sea level data. Continuous observation of sea level has allowed the monitoring of the 1976 and the 1982-83 El Niño events, has demonstrated the very large space and time scales of sea level variations (Wyrтки, 1979b), and has allowed the monitoring of the changing intensity of ocean currents (Wyrтки, 1974).

Demand for sea level data has increased dramatically. The Committee on Climatic Changes and the Ocean (CCCCO) of the Intergovernmental Oceanographic Commission (IOC) has stressed the importance of sea level data for monitoring climatic effects (IOC, 1983a). The Permanent Service for Mean Sea Level (PSMSL) has completed an inventory of existing sea level records (IOC, 1983b and Lutjeharms, 1983) and has increased its archiving of more recent records of monthly and annual mean sea level. Scientists need access not only to monthly mean values but to daily mean and hourly readings for their research. The Integrated Global Ocean Services System (IGOSS) has drafted a plan for the real-time transmission of sea level data and for a pilot project to implement such a plan in the Pacific (IGOSS, 1983).

This IGOSS Sea Level Pilot Project (ISLPP) was established by the International Oceanographic Commission (IOC) and the World Meteorological Organization (WMO). They created a Special Oceanographic Center (SOP) for mean sea level in the Pacific at the University of Hawaii. The first real-time map of Pacific sea level was issued in August 1982.

To facilitate comparison of these synoptic maps of sea level topography with past data we include in this report monthly maps of sea level anomaly for the Pacific Ocean for the period January 1975 to December 1981. In a separate report (Wyrтки, 1984) similar maps were issued for the period January 1982 to December 1982, which covers the 1982/83 El Niño event.

Even if satellite altimetry provides information on the topography of the sea surface over the entire globe in the next decade, such a system will require verification by means of direct sea level observations. Moreover, it is highly questionable whether satellite altimetry will ever be able to measure mean sea level changes with an accuracy of about 2 cm over a time span of several decades, as land-based gauges do.

DATA PROCESSING

During 1974/75 a network of sea level stations was established on selected islands in the Pacific to monitor sea level variations (Wyrski, 1979a). Data from the 27 stations of this network are used together with data from 8 island-based stations operated by the National Oceanographic and Atmospheric Administration (NOAA), several stations along the west coast of the Americas, in the Philippines, and on islands south of Japan. Only a few coastal stations were used to avoid an overemphasis on the periphery of the area covered. The stations are listed in Table 1 and their locations are shown in Figure 1.

Experience has shown that large-scale events with time scales from months to years can be conveniently documented by the use of monthly mean sea level data (Wyrski, 1979b). The monthly mean values of sea level height (SLH) observed at each station were not corrected for atmospheric pressure because the variability of monthly mean atmospheric pressure is small in the tropical ocean and because it is largely uncorrelated with sea level in the spectral range of interest (Roden, 1963; Luther, 1982).

Because most of the sea level stations used in this study have been in operation only since 1975, all data have been referred to the mean sea level (MSL) at each station for the seven-year period 1975 to 1981. Trends have not been removed because of the shortness of this period. In view of the presence of short-term climatic fluctuations with periods of several years, the identification and removal of a trend requires data over several decades (Barnett, 1983). Almost all stations show a weak annual cycle, which has been documented by Wyrski and Leslie (1980). At most stations in the tropical Pacific the amplitude of the first harmonic of the annual cycle is less than 50 mm but would be apparent in maps contoured at that interval. Consequently the mean annual cycle (MAC) for the period 1975 to 1981 was computed for each station and then removed from the sea level values. This procedure results in monthly mean sea level anomalies (SLA), which are defined by the relation

$$SLA = SLH - MSL - MAC.$$

Maps of sea level anomaly for each month from January 1975 to December 1981 are shown in Figures 2 to 85. The maps show the sea level anomaly at each station in millimeters were contoured by use of a computer program after interpolation on a grid of 2 degrees of latitude and 10 degrees of longitude. The data set was subjected to an analysis by means of empirical orthogonal functions by Wenzel (1984).

The accuracy of sea level observations from well-tended gauges is relatively high, and values between 10 and 20 mm are usually quoted for the accuracy of a monthly mean value. This value of the accuracy of the measurements might be viewed in relation to the data noise resulting from

Table 1. List of sea level stations in the Pacific.

NUM	STATION NAME	LOCATION	LAT	LONG
1	SAN DIEGO	CALIFORNIA	32-42N	117-10W
2	ACAPULCO	MEXICO	16-50N	099-55W
3	SANTA CRUZ	ECUADOR	00-27S	090-17W
4	LA LIBERTAD	ECUADOR	02-12S	080-55W
5	CALLAO	PERU	12-03S	077-09W
6	TALCAHUANO	CHILE	36-42S	073-06W
7	JUAN FERNANDEZ	CHILE	33-37S	078-50W
8	LEGASPI	PHILIPPINES	13-09N	123-45E
9	DAVAO	PHILIPPINES	07-05N	125-38E
10	TOWNSVILLE	AUSTRALIA	19-16S	146-50E
11	NORFOLK	AUSTRALIA	29-04S	167-56E
12	NOUMEA	NEW CALEDONIA	22-18S	166-26E
13	PORT VILLA	NEW HEBRIDES	17-44S	168-19E
14	SAIPAN	MARIANAS	15-14N	145-44E
15	GUAM	MARIANAS	13-26N	144-39E
16	YAP	CAROLINES	09-31N	138-08E
17	MALAKAL	CAROLINES	07-20N	134-28E
18	TRUK	CAROLINES	07-27N	151-51E
19	PONAPE	CAROLINES	06-59N	158-14E
20	KAPINGAMARANGI	CAROLINES	01-06N	154-47E
21	ENIWETOK	MARSHALL	11-26N	162-23E
22	KWAJALEIN	MARSHALL	08-44N	167-44E
23	NAURU	GILBERT ISL.	00-32S	166-54E
24	TARAWA	GILBERT ISL.	01-22N	172-56E
25	MAJURO	MARSHALL	07-05N	171-23E
26	JOHNSTON	DETACHED	16-45N	169-31W
27	WAKE	DETACHED	19-17N	166-37E
28	MIDWAY	DETACHED	28-13N	177-22W
29	FRENCH FRIGATE SHOAL	HAWAII	23-52N	166-71W
30	HONOLULU	HAWAII	21-18N	157-52W
31	HILO	HAWAII	19-44N	155-04W
32	RAROTONGA	COOK ISL.	21-12S	159-46W
33	CANTON	PHOENIX	02-48S	171-43W
34	PENRHYN	DETACHED	09-01S	158-04W
35	JARVIS	LINE	00-23S	160-00W
36	CHRISTMAS	LINE	01-57N	157-28W
37	FANNING	LINE	03-52N	159-22W
38	MALDEN	LINE	04-03S	154-59W
39	HIVA OA	MARQUESAS ISL.	09-49S	139-02W
40	PAGO PAGO	SAMOA	14-17S	170-41W
41	PAPEETE	SOCIETY	17-32S	149-34W
42	FUNAFUTI	ELLICE ISL.	08-31S	179-12E
43	RIKITEA	GAMBIER	23-08S	134-57W
44	SUVA	FIJI	18-08S	178-26E
45	EASTER	EASTER ISL.	27-09S	109-29W
46	CHICHIJIMA	JAPAN	27-05N	142-11E
47	NAHA	JAPAN	26-13N	127-40E
48	NAZE	JAPAN	28-23N	129-30E
49	HONIARA	SOLOMONS	09-26S	159-57E
50	RABUL	NEW GUINEA	04-12S	152-11E
51	ANEWA BAY	NEW GUINEA	06-13S	155-38E
52	CABO SAN LUCAS	MEXICO	22-53N	109-54W
53	BUENAVENTURA	ECUADOR	03-54N	077-05W

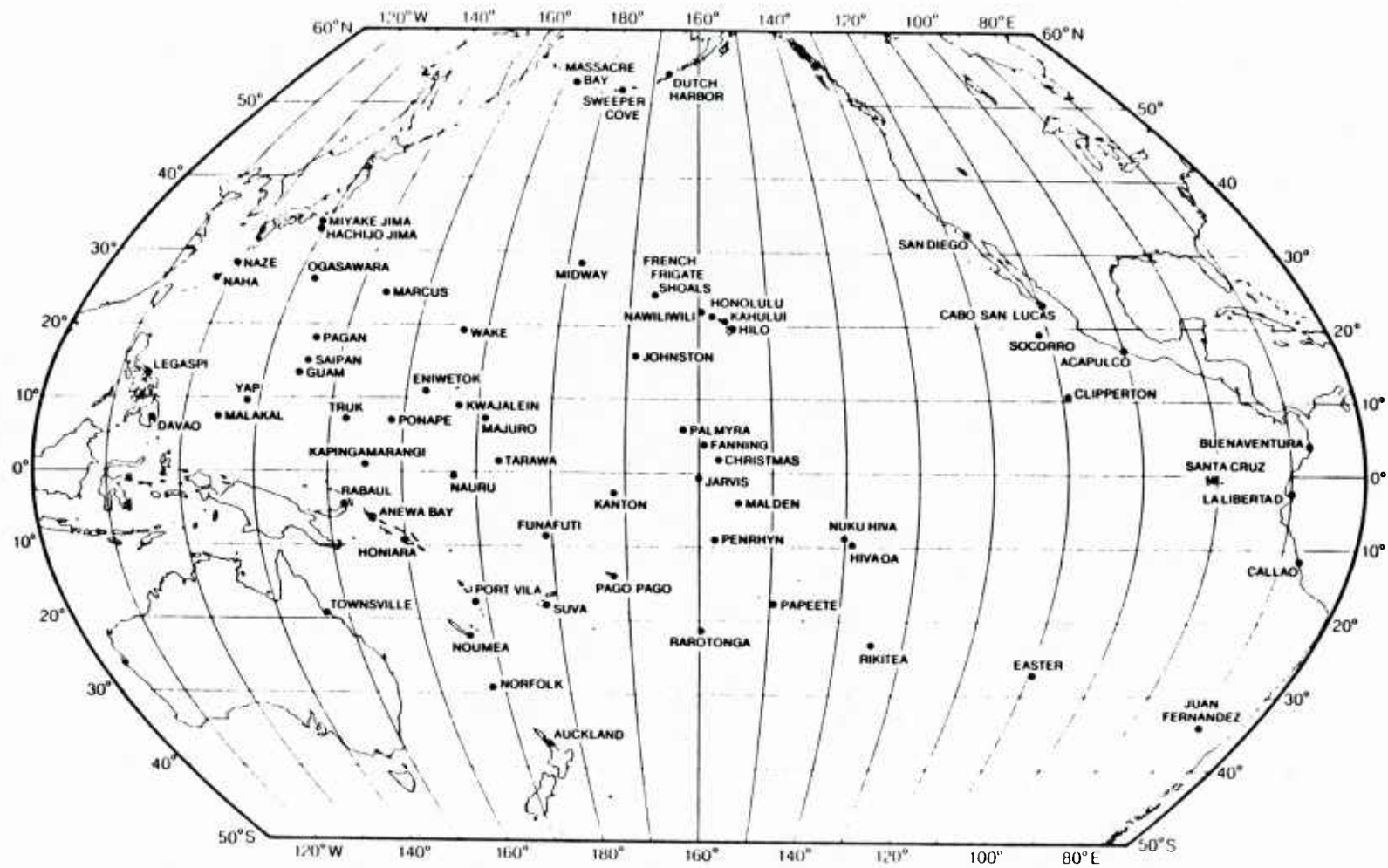


Figure 1. Locations of sea level stations in the Pacific.

local processes influencing each station. A comparison of nearby stations within a few hundred kilometers shows that the root-mean-square differences of monthly mean sea levels between stations are about 30 mm. This value is, of course, larger than the accuracy of the measurements but smaller than the standard deviation of monthly mean sea level at a given station, which is typically 50 mm (Wyrski and Leslie, 1980). Consequently, a contour interval of 50 mm was selected for the monthly maps of sea level anomaly. Deviations in excess of this value must be considered significant.

DISCUSSION

A brief inspection of the 84 maps of sea level anomalies reveals three important features: (i) large horizontal coherence in the sea level anomalies with space scales of several thousand km, (ii) larger coherence scales in the east-west than in the north-south direction, and (iii) anomalies coherent over many months, indicating a dominance of low-frequency variations. The principal fluctuations of the sea level field are on large scales and low frequencies.

A more detailed inspection provides some insight into the development of individual sea level anomalies. During 1975 a positive sea level anomaly develops in the western Pacific, and a negative anomaly develops along the coast of the Americas, which leads to an increased upward tilt of the sea surface from east to west. A maximum positive anomaly of +21 cm is reached in October at Truk and in January 1976 at Honiara (+18 cm). A maximum negative anomaly (-13 cm) occurs at La Libertad in October. This development seems to be typical for the buildup prior to the onset of El Niño.

The El Niño event of 1976 is marked by a rapid decrease of the positive sea level anomaly in the western Pacific during the first half of the year and by the development of a positive anomaly along the Americas. It reaches a peak of +12 cm at the Galapagos Islands in June 1976. From May onwards a negative anomaly forms in the western Pacific. It increases in strength to -24 cm in September and spreads slowly toward the central equatorial Pacific, until it fades away by March 1977. During the 1976 El Niño event no extensive negative sea level anomaly develops to the south of the equator, but it was a major occurrence during the 1983 event.

During 1977 the amplitudes of sea level anomalies remain small, usually less than 10 cm, but there is still a pronounced spacial coherence, especially in the east-west direction. From December 1977 to March 1978 a negative anomaly develops between New Guinea and Tahiti with a peak value of -15 cm at Honiara in February.

Starting in May 1978 a large positive anomaly forms in the North Pacific stretching from the Philippines to the Hawaiian Islands. The anomaly reaches a peak value of +15 cm at Wake in July and then apparently shifts northward with maximum sea level anomalies at Midway and near Japan in September.

The year 1979 is characterized by prevailing negative anomalies, which start to develop in November and December 1978 in the southwest Pacific and in January 1979 in the area of the North Equatorial Current. The two anomalies merge in March, never become very strong, but persist until October. This was the year of the Hawaii to Tahiti Shuttle Experiment, when ocean conditions in the Central Pacific happened to be "normal" (Wyrski and Kilonsky, 1984).

In April 1980 positive sea level anomalies develop in the central equatorial Pacific, indicating a weakening of equatorial upwelling (Wyrski and Eldin, 1982). These anomalies last until August 1980. During the period January to August 1980 sea level in the western Pacific is slightly below normal and in the eastern Pacific it is slightly above normal, indicating a weakening of the normal east-west tilt of the sea surface and the presence of weaker trade winds.

From December 1980 to May 1981 positive sea level anomalies develop in the central Pacific from the Hawaiian Islands toward the equator. A weak anomaly persists in the western Pacific from March through June. Starting in August 1981 positive sea level anomalies develop near 10°N and east of New Guinea. By December most of the western equatorial Pacific has above normal sea level, indicating the buildup of warm water before the 1982 El Niño event.

ACKNOWLEDGMENTS

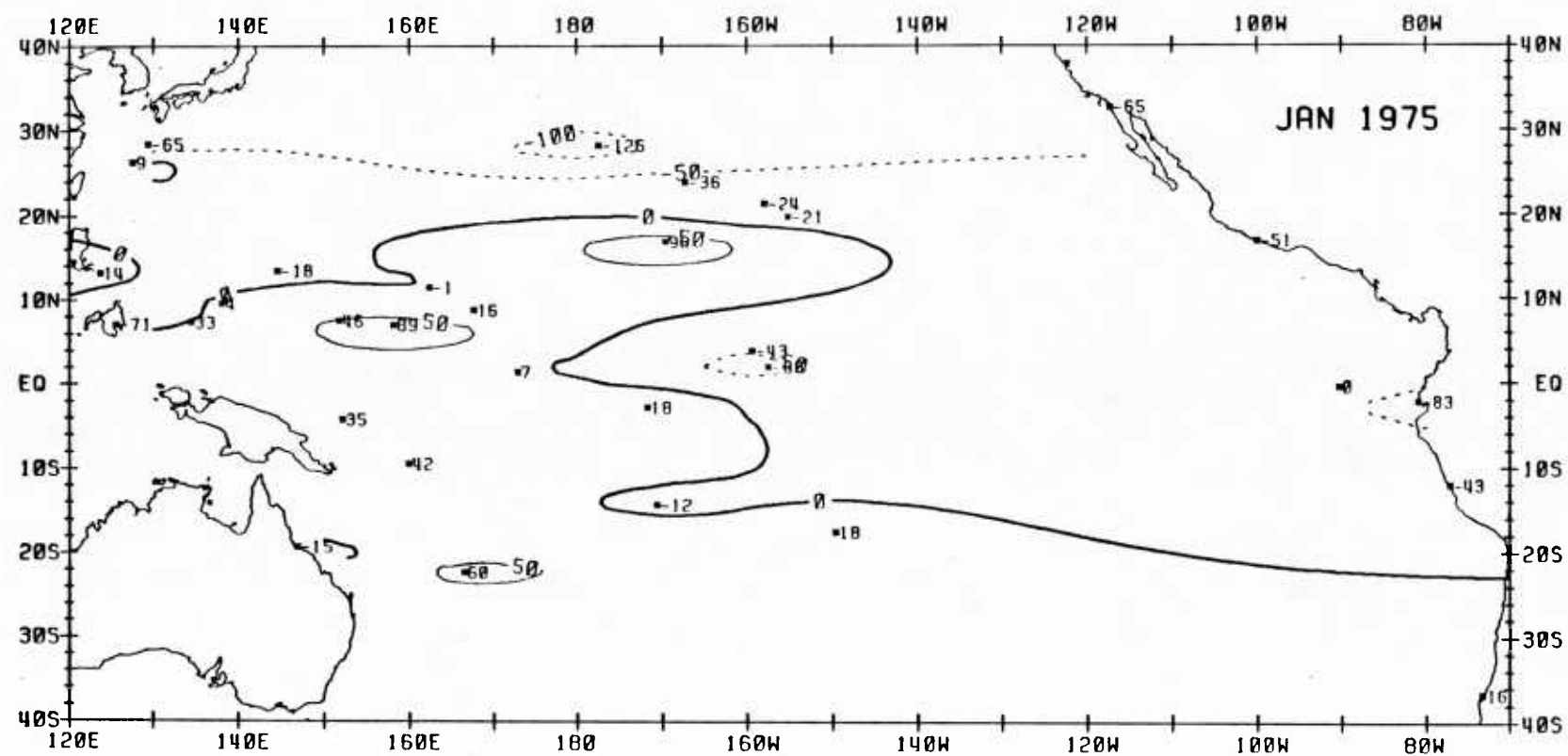
The research has been supported by the National Oceanic and Atmospheric Administration under JIMAR Cooperative Agreement NA80RAH00002 as part of the IGOSS Sea Level Pilot Project; this support is gratefully acknowledged.

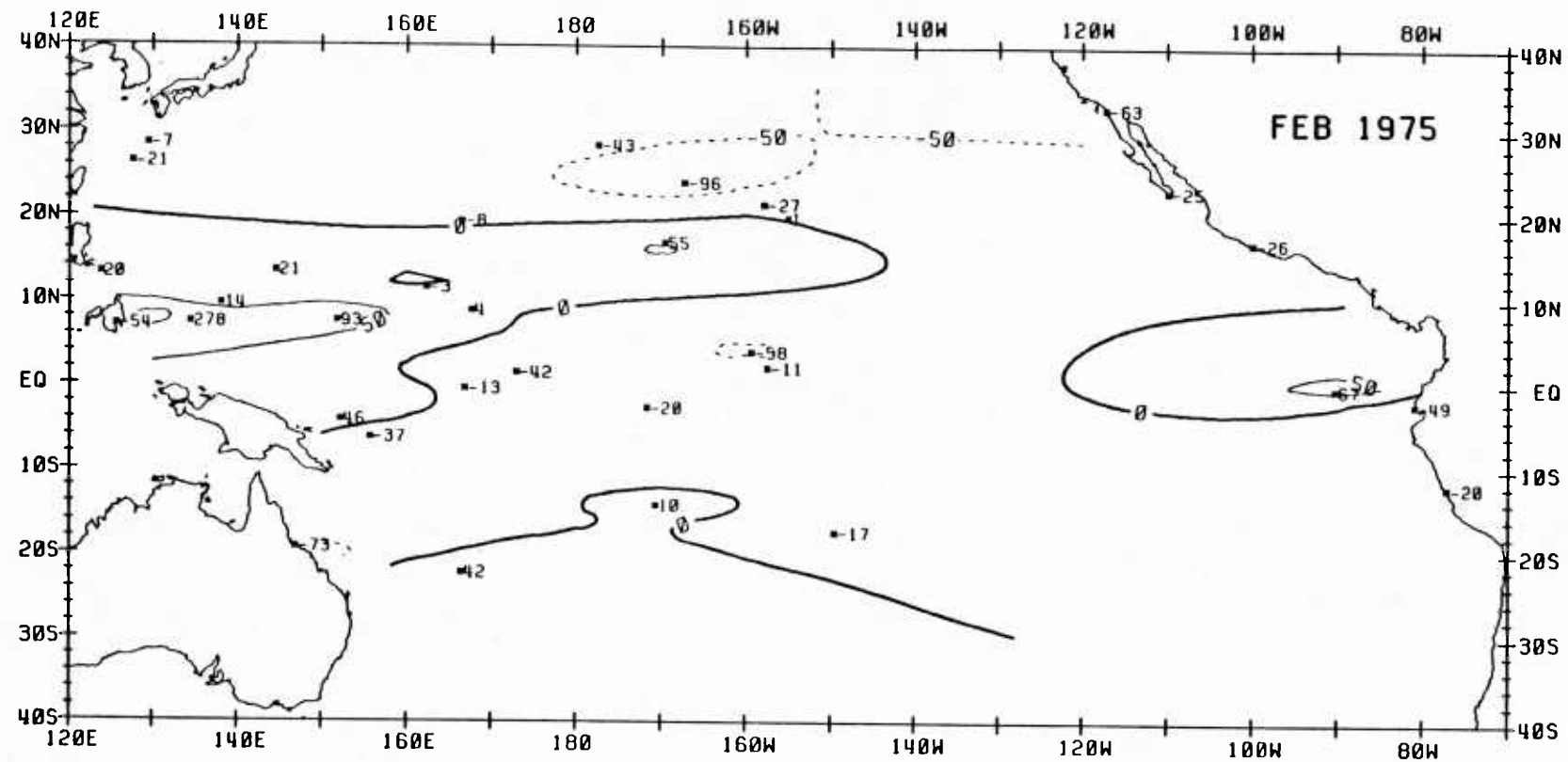
REFERENCES

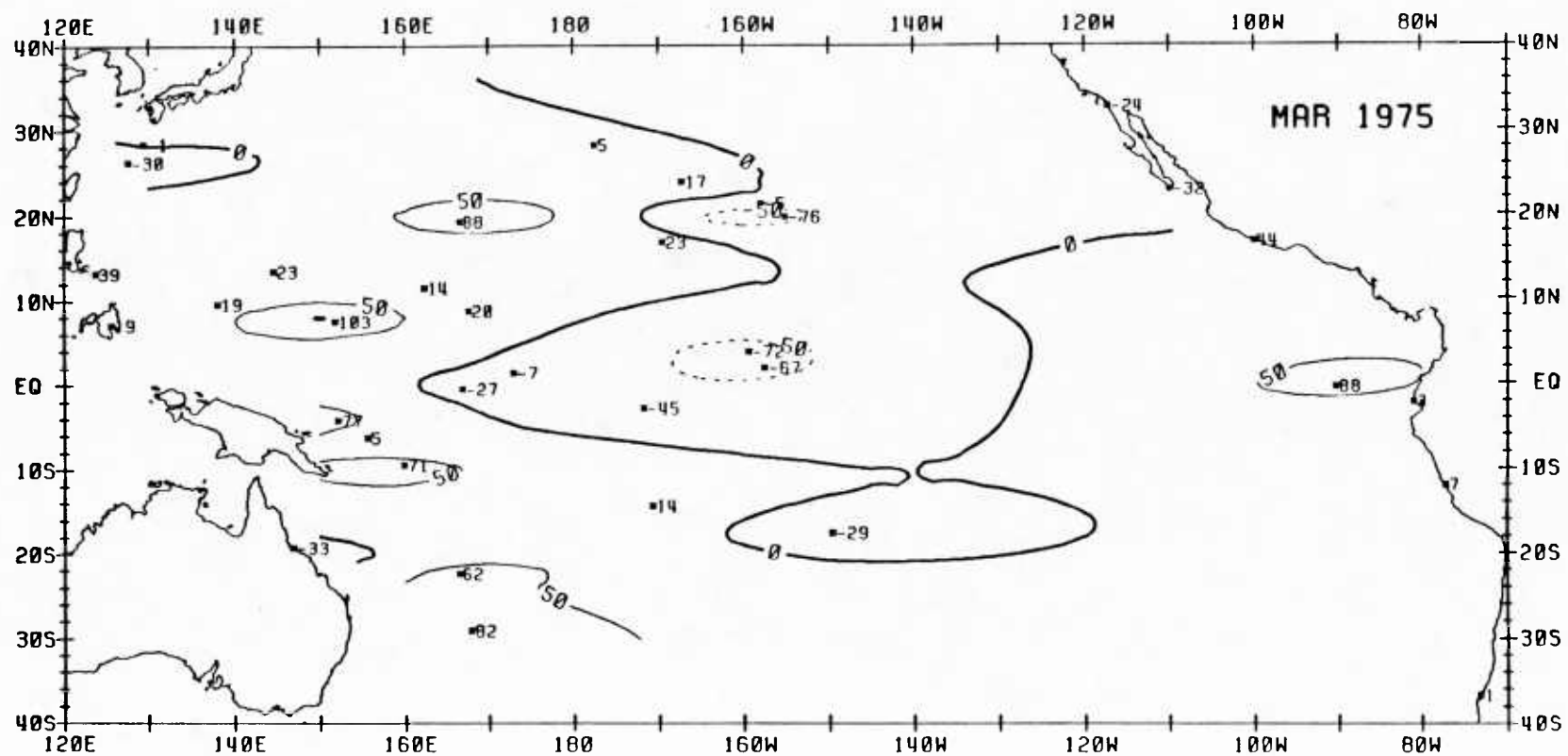
- Barnett, T. P., 1983. Recent changes in sea level and their possible causes. *Climatic Change*, v. 5, p. 15-38.
- IGOSS, 1983. Third Session Summary Report, Joint IOC/WMO Working Committee for IGOS, Paris, 33 pp.
- IOC, 1983a. Fourth Session Summary Report, Committee on Climatic Changes and the Ocean, Paris, 86 pp.
- IOC, 1983b. Operational sea-level stations, Intergovernmental Oceanographic Commission technical series, no. 23, UNESCO, 40 pp.
- Luther, 1982. Evidence of a 4-6 day barotropic, planetary oscillation of the Pacific Ocean. *J. Phys. Oceanogr.*, v. 12, no. 7, p. 644-657.
- Lutjeharms, 1983. Sea Level in the world ocean, Parts I-VII, CSIR T/SEA 8303/1, National Research Institute for Oceanology, Stellenbosh, South Africa.
- Roden, G. I., 1963. On sea level, temperature and salinity variations in the central tropical Pacific and on Pacific Ocean islands. *J. Geophys. Res.*, vo. 68, no. 2, p. 455-472.
- Wenzel, J., 1984. Empirical orthogonal function analysis of sea level fluctuations in the tropical Pacific Ocean. Master's Thesis, Univ. of Hawaii, Honolulu.
- Wyrtki, K., 1974. Sea level and the seasonal fluctuations of the equatorial currents in the western Pacific Ocean. *J. Phys. Oceanogr.*, v. 10, no. 1, p. 91-103.
- Wyrtki, K., 1979a. Sea level variations; monitoring the breath of the Pacific. *EOS*, v. 60, no. 3, p. 25-27.
- Wyrtki, K., 1979b. The response of sea surface topography to the 1976 El Nino, *J. Phys. Oceanogr.*, v. 9, p. 1223-1231.
- Wyrtki, K., 1984. Monthly maps of sea level in the Pacific during the El Nino of 1982 and 1983. In: *Time Series of Ocean Measurements*, Vol. II, I.O.C. Tech. Series, no. xx (in press).
- Wyrtki, K. and W. Leslie, 1980. The mean annual variation of sea level in the Pacific Ocean. Univ. Hawaii, Ref. HIG-80-5, 159 pp.
- Wyrtki, K. and G. Eldin, 1982. Equatorial upwelling events in the Central Pacific. *J. Phys. Oceanogr.*, v. 12, no. 9, p. 984-988.

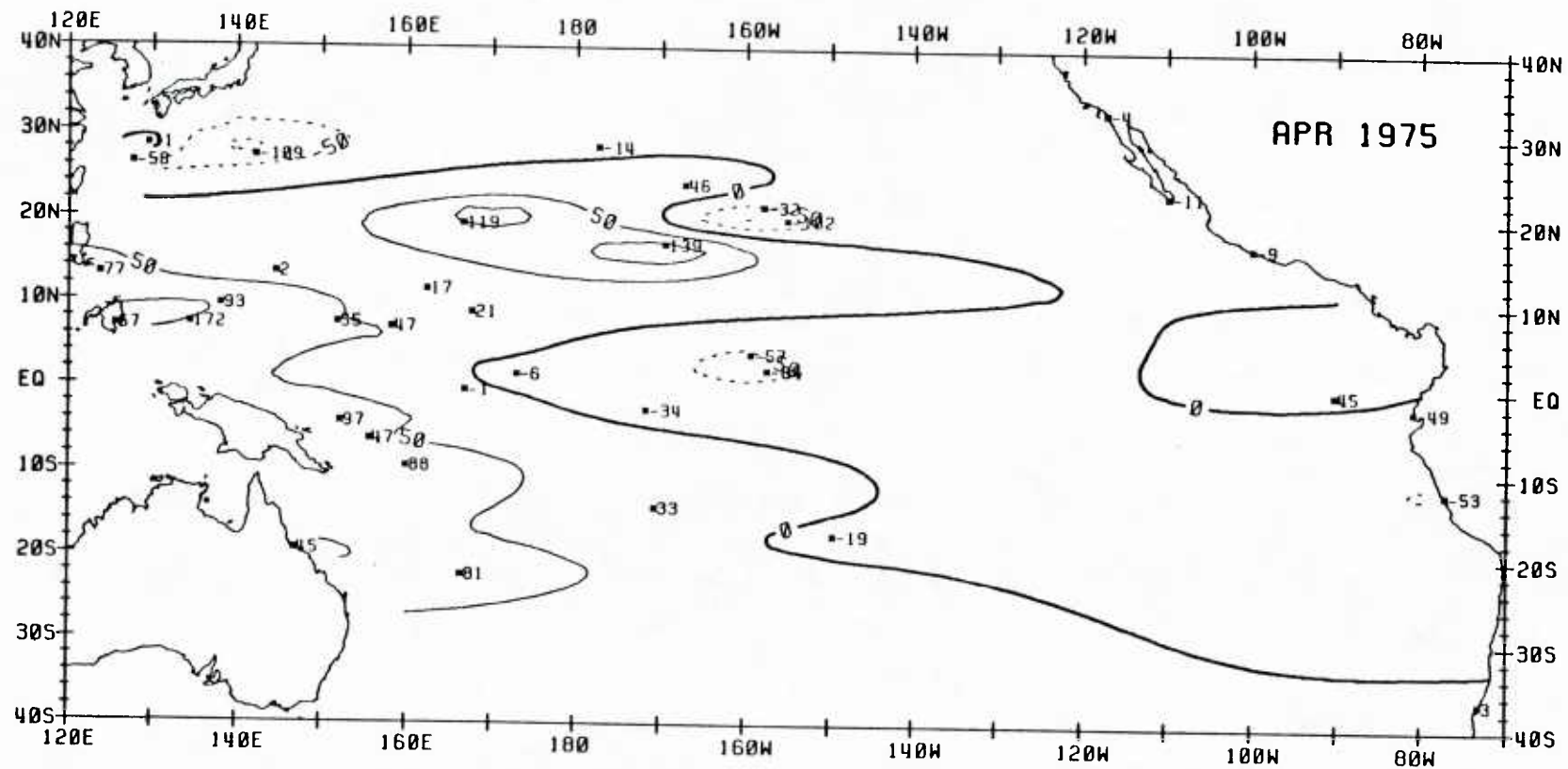
Wyrtki, K. and B. Kilonsky, 1984. Mean water and current structure during the Hawaii to Tahiti Shuttle Experiment. J. Phys. Oceanogr., v. 14, no. 2, 242-254.

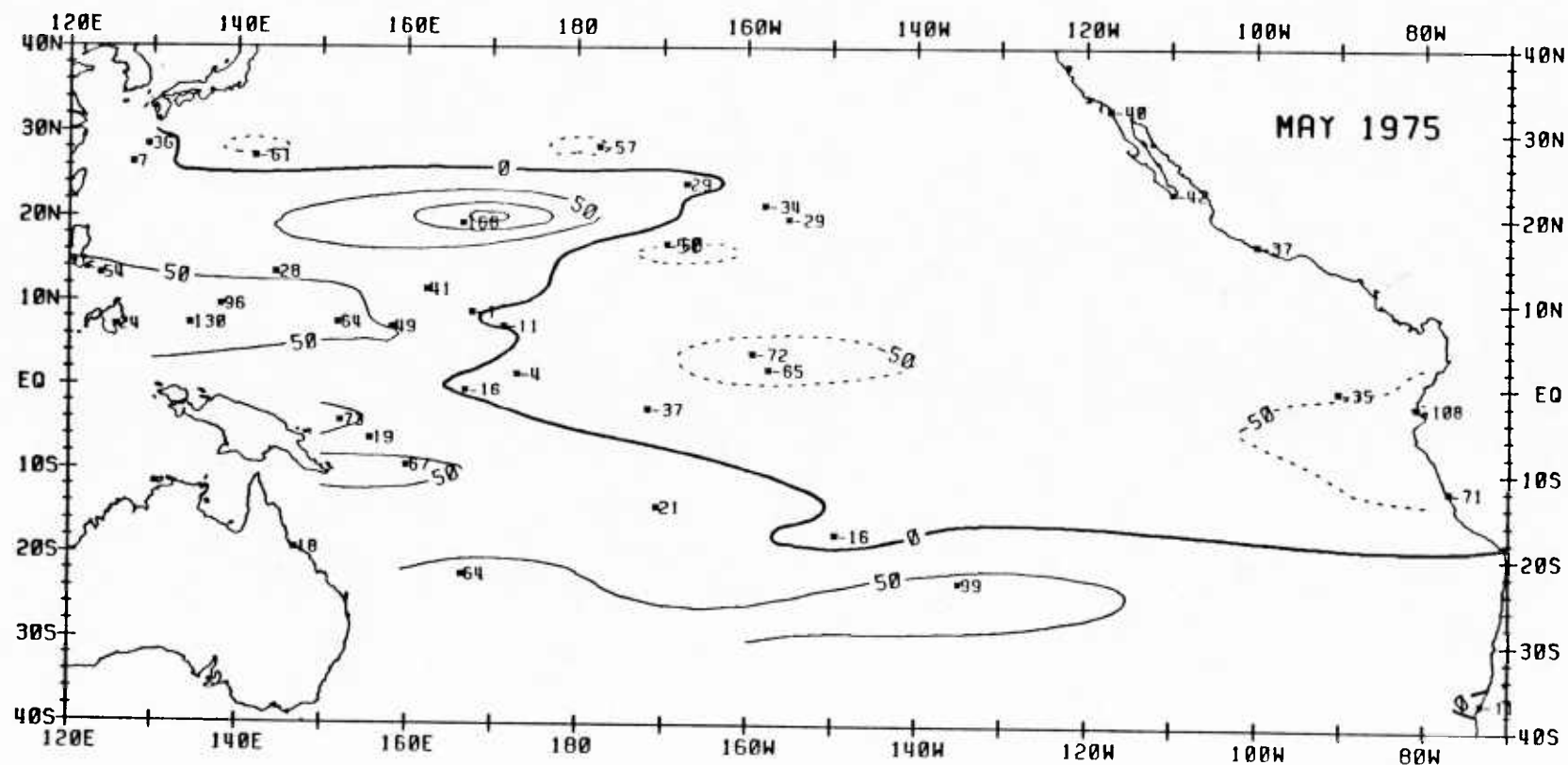
Monthly Maps of Sea Level Anomalies for 1975 through 1981

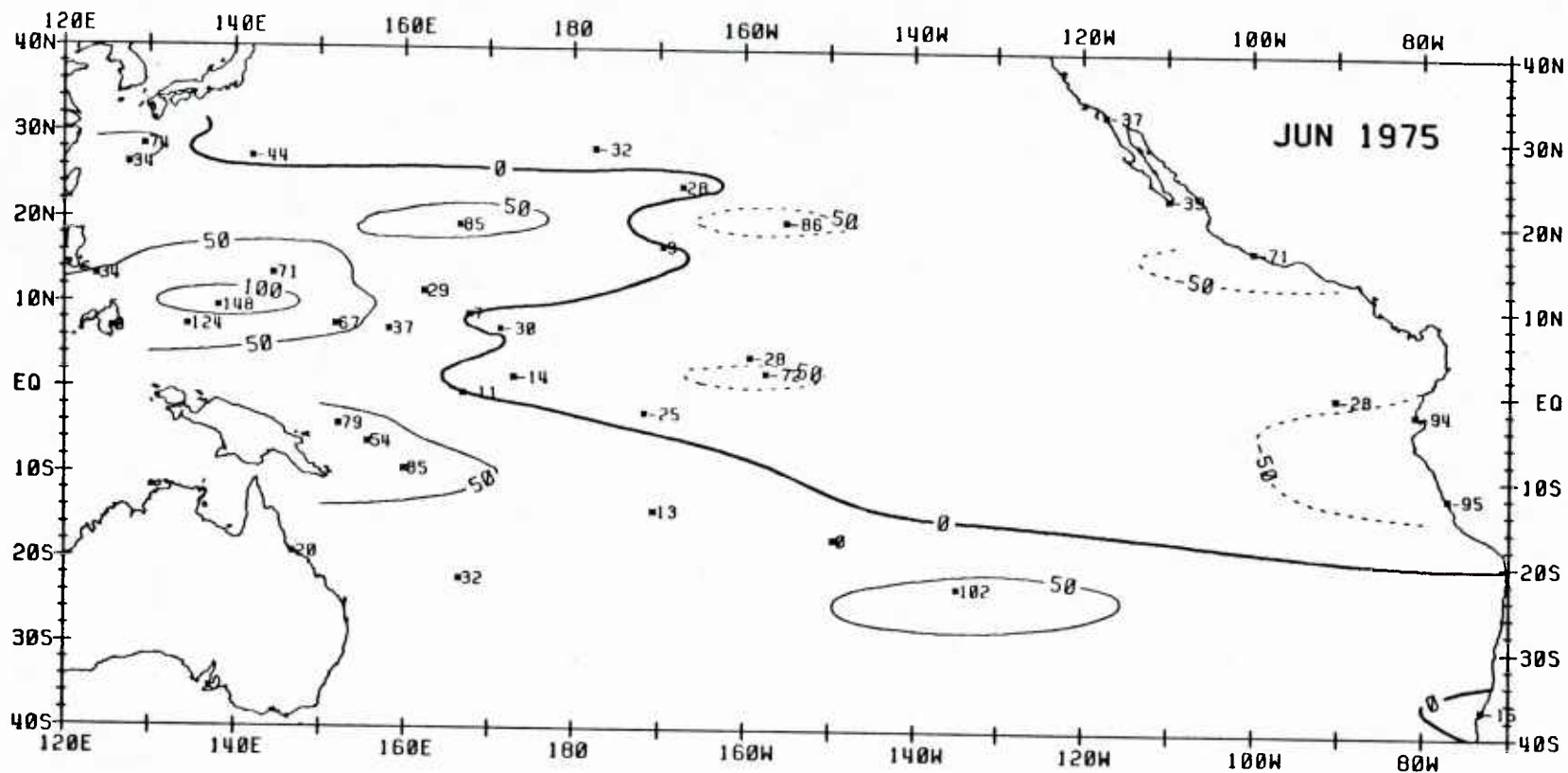


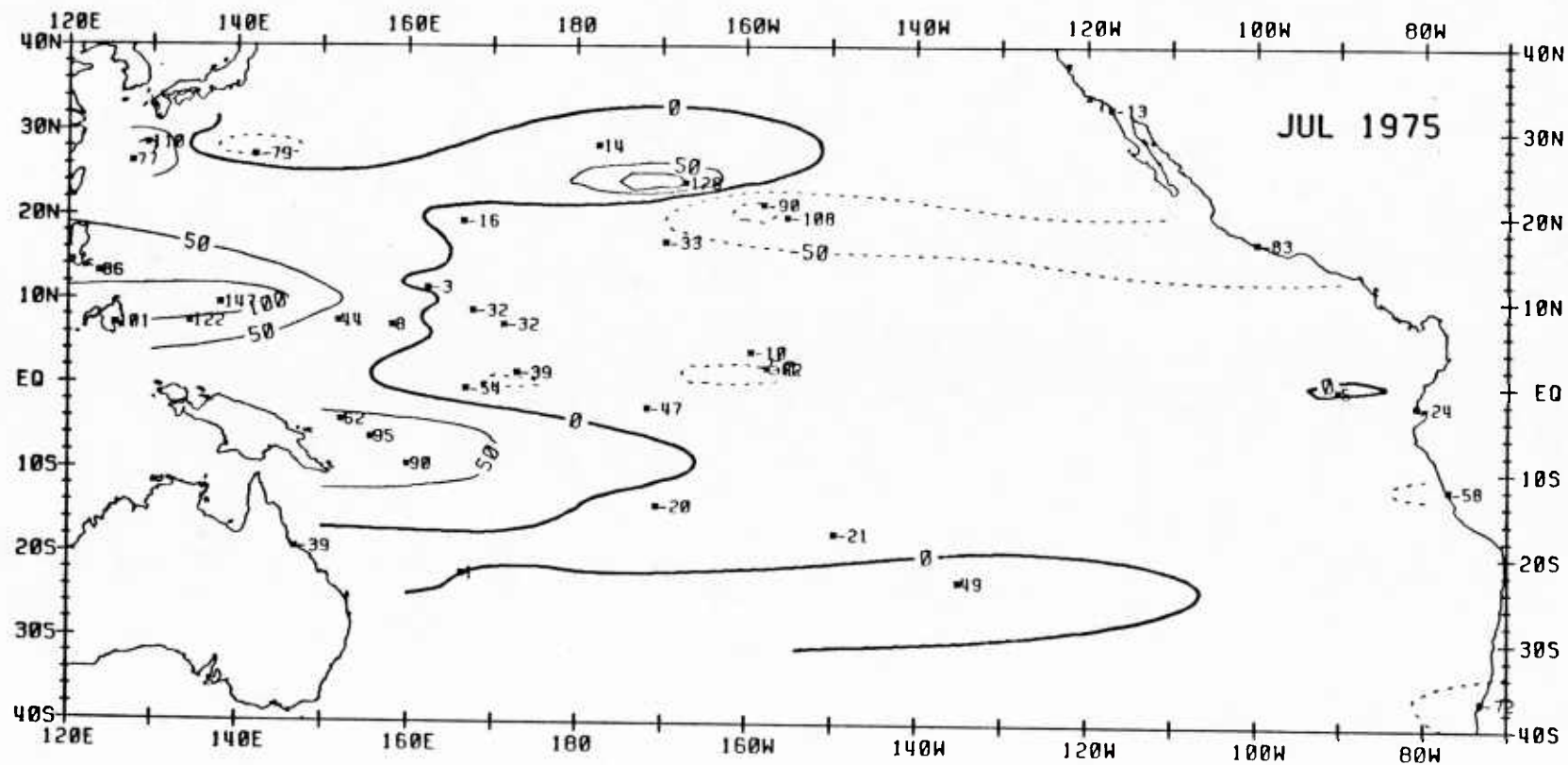


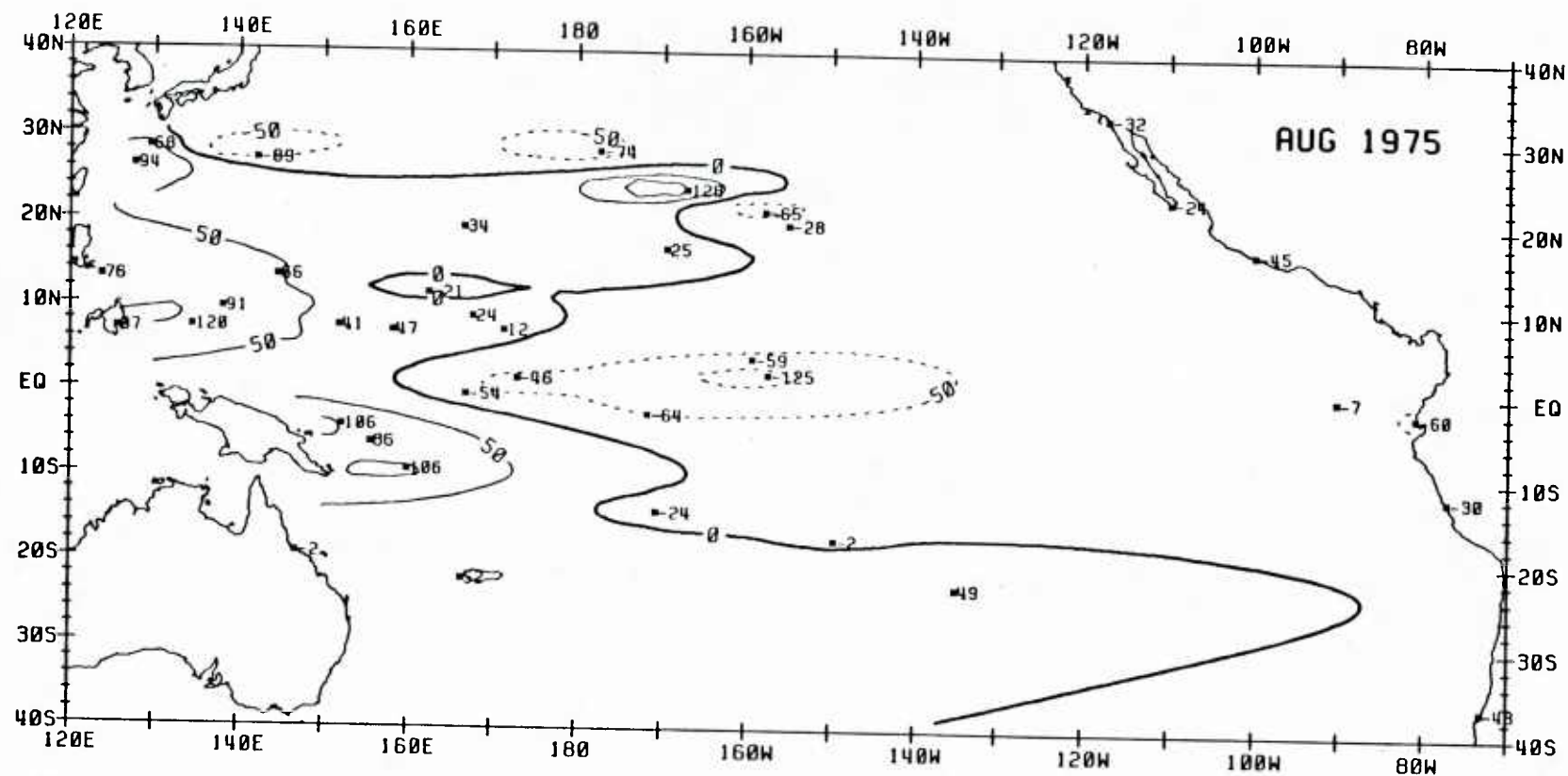


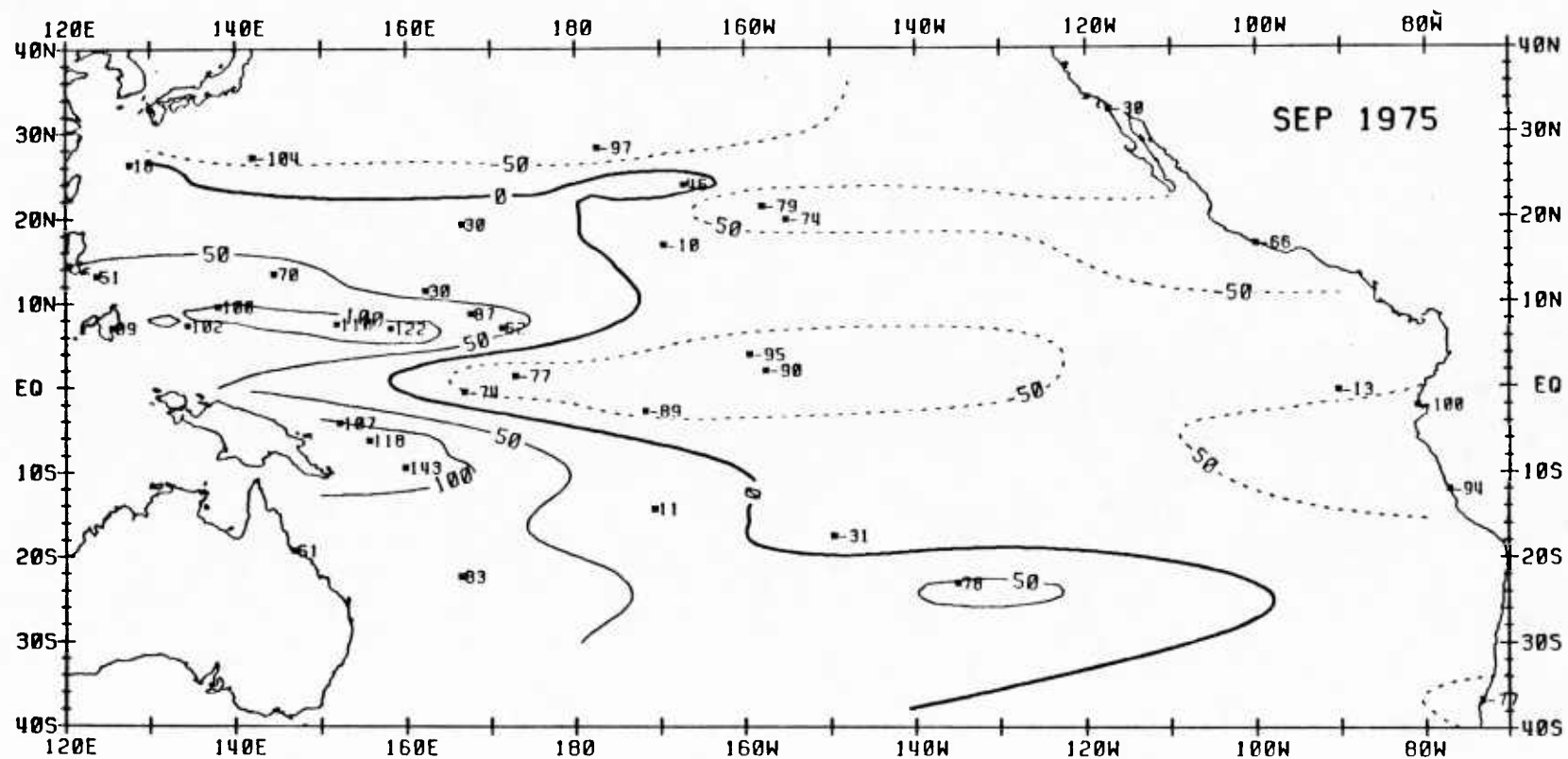


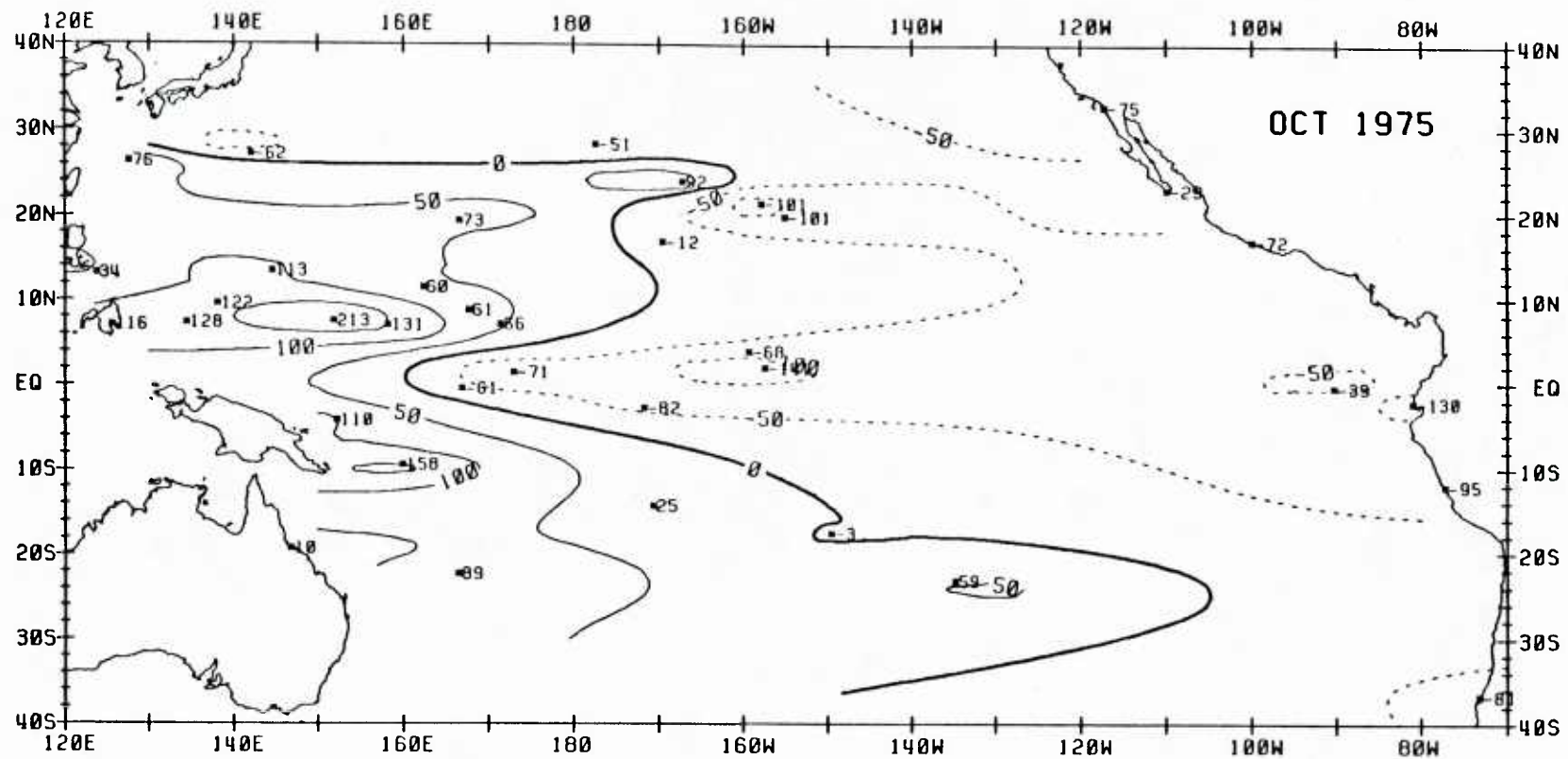


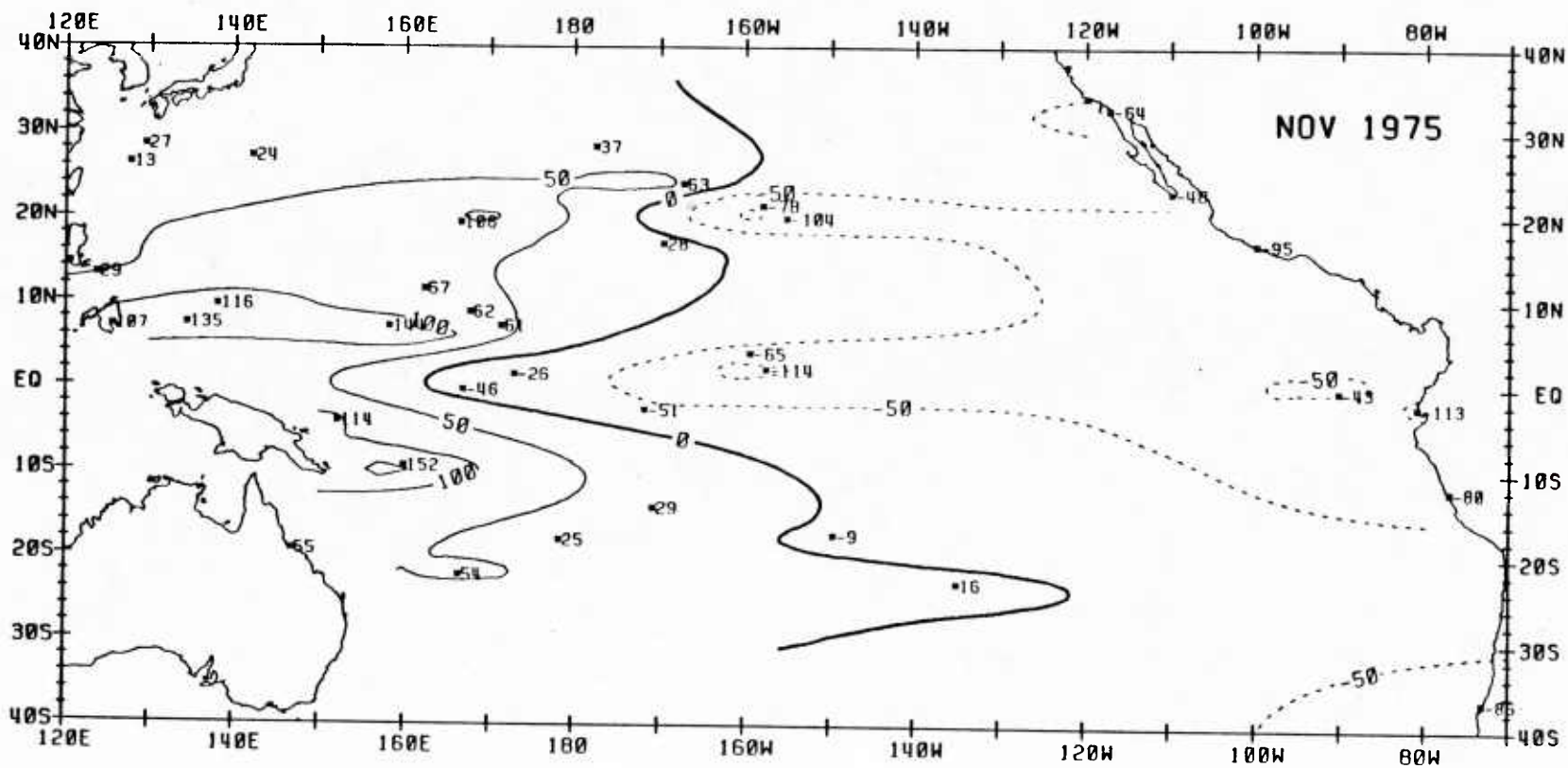


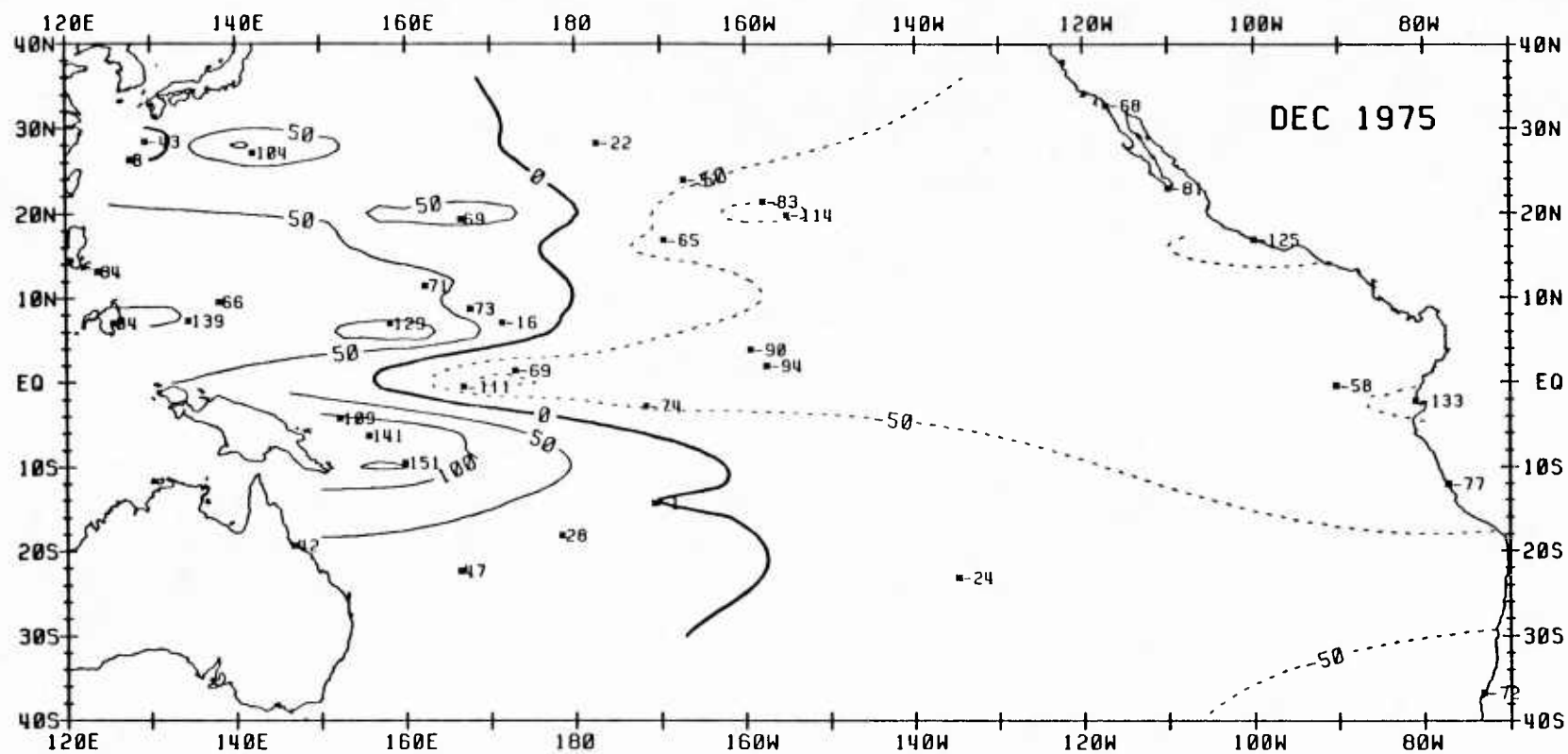


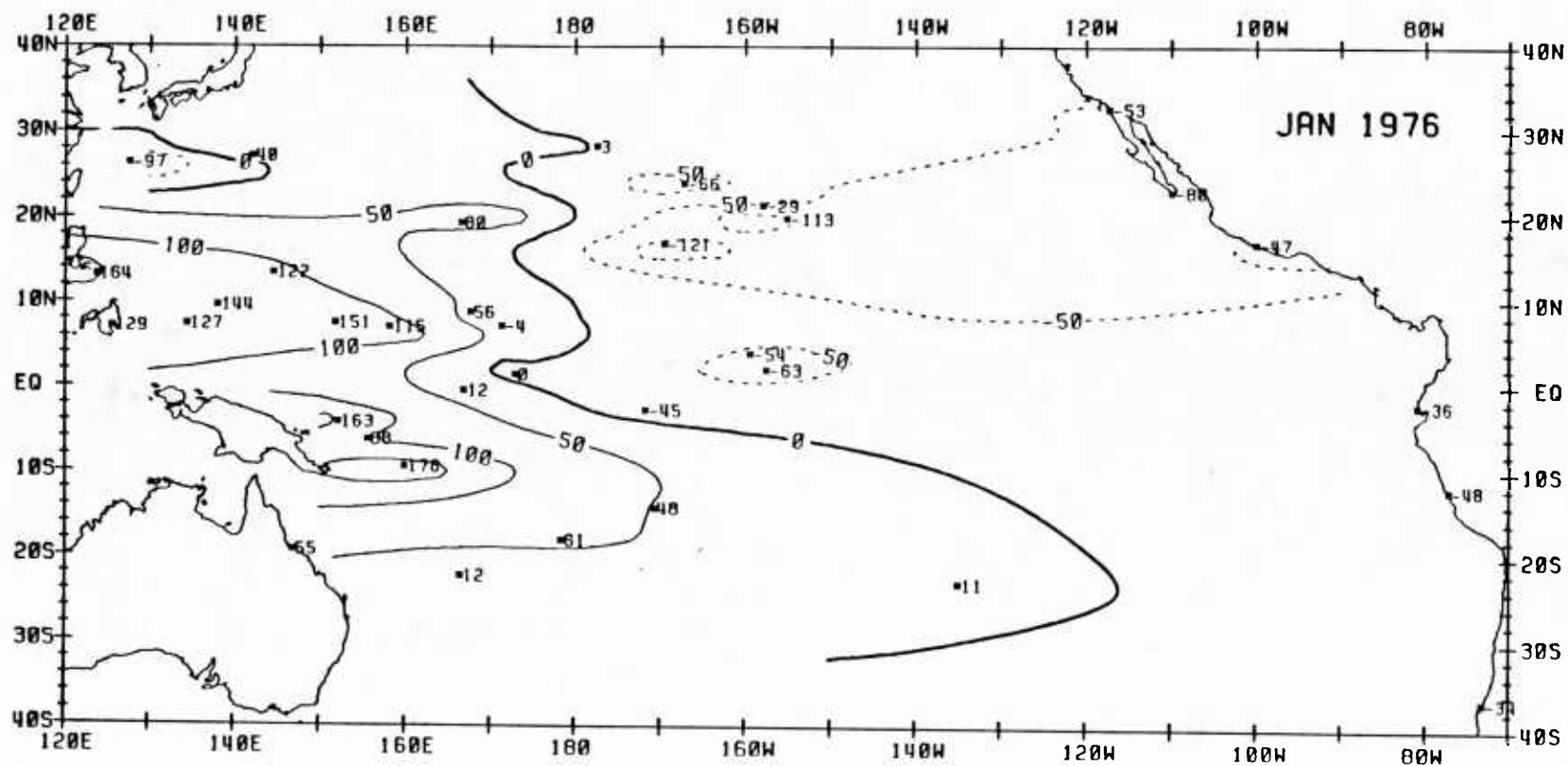


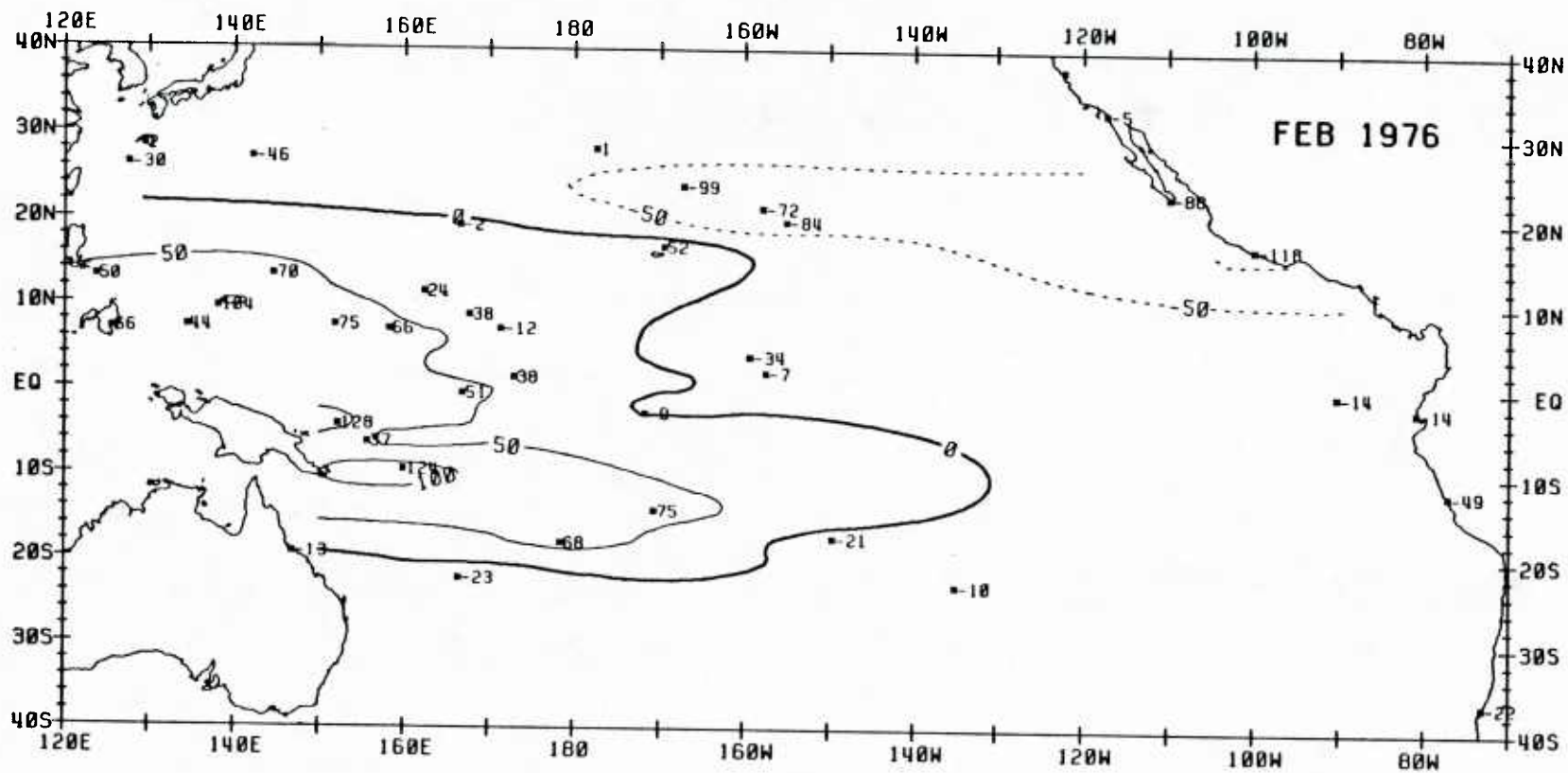


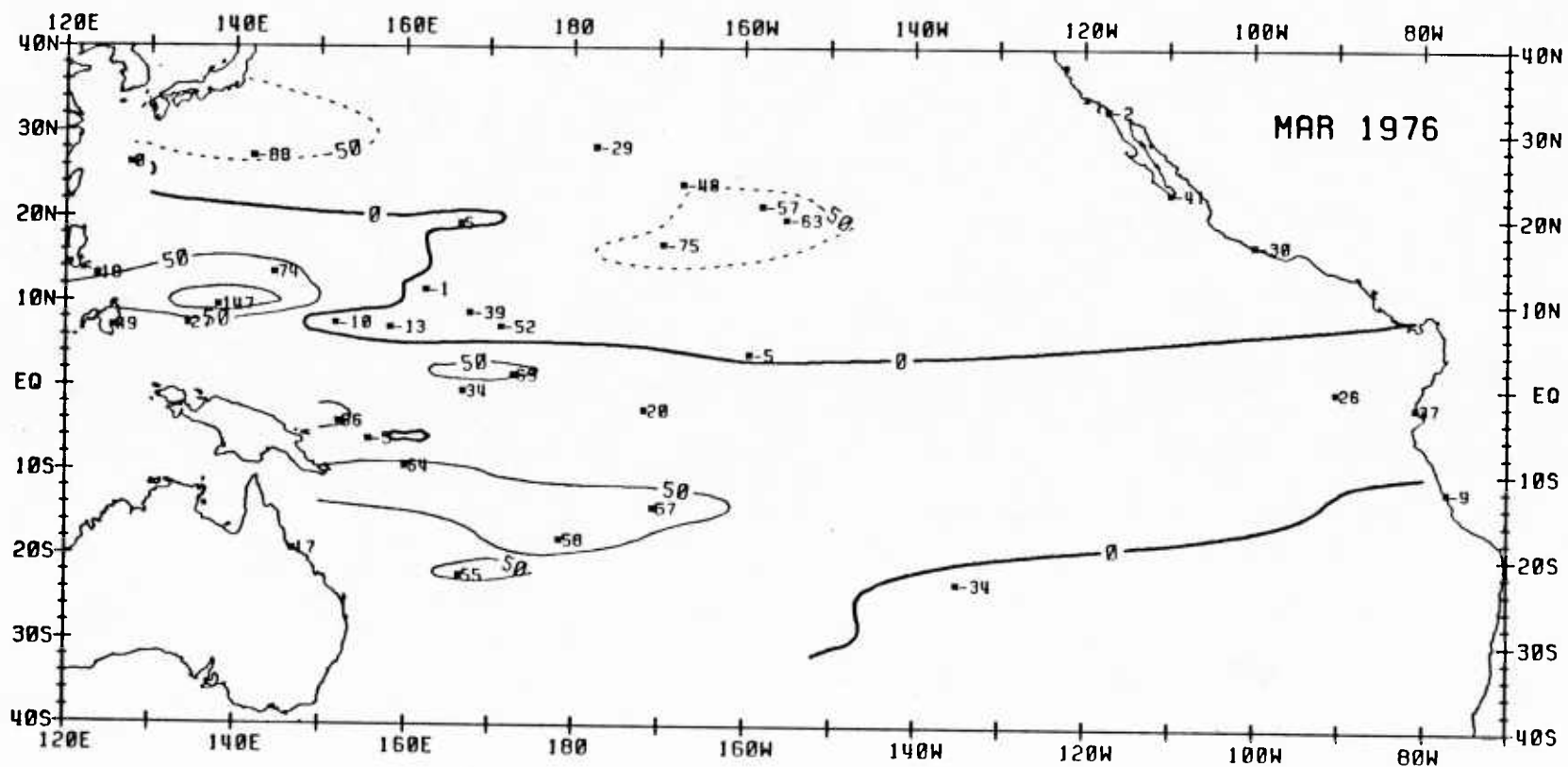


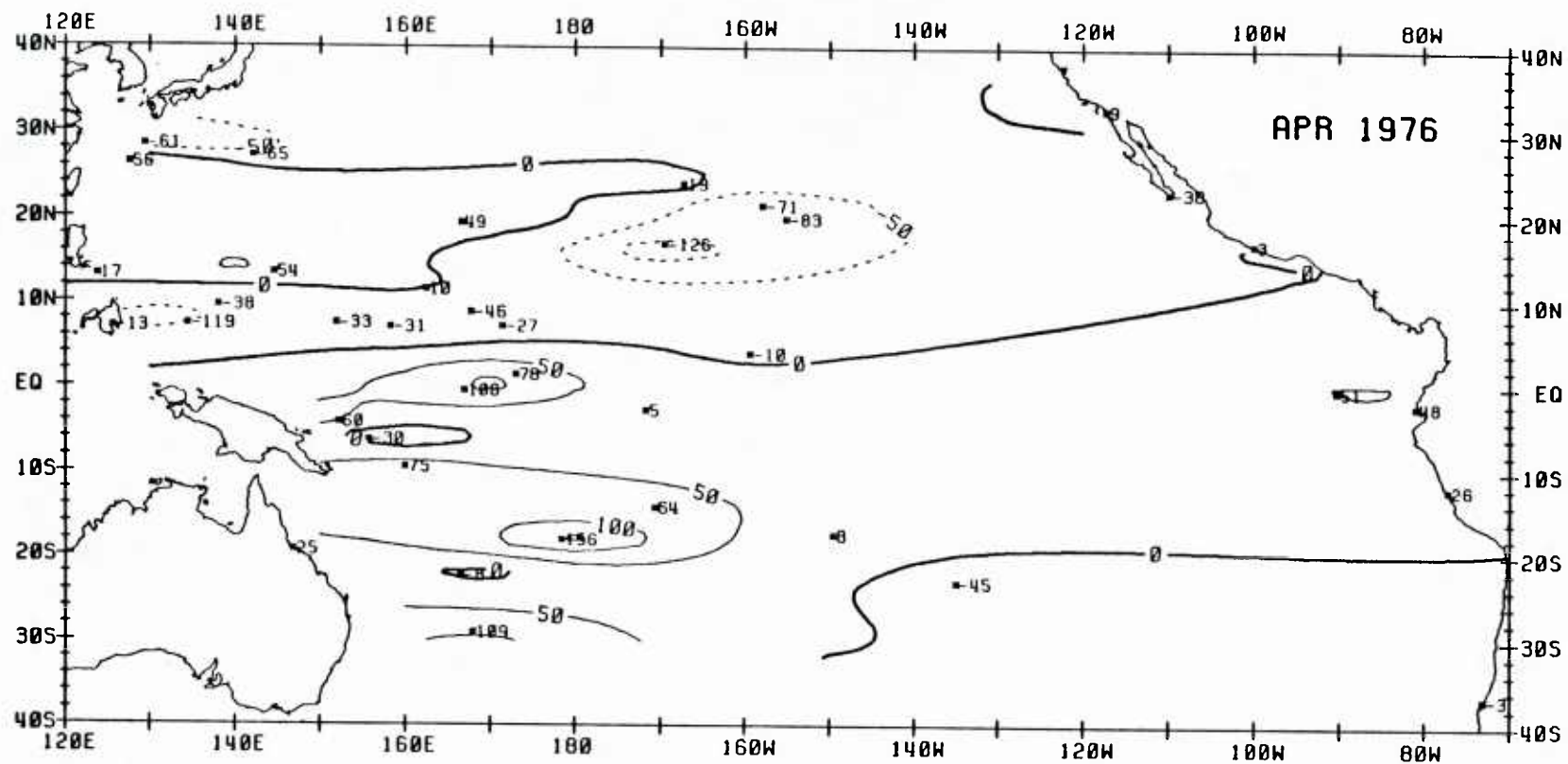


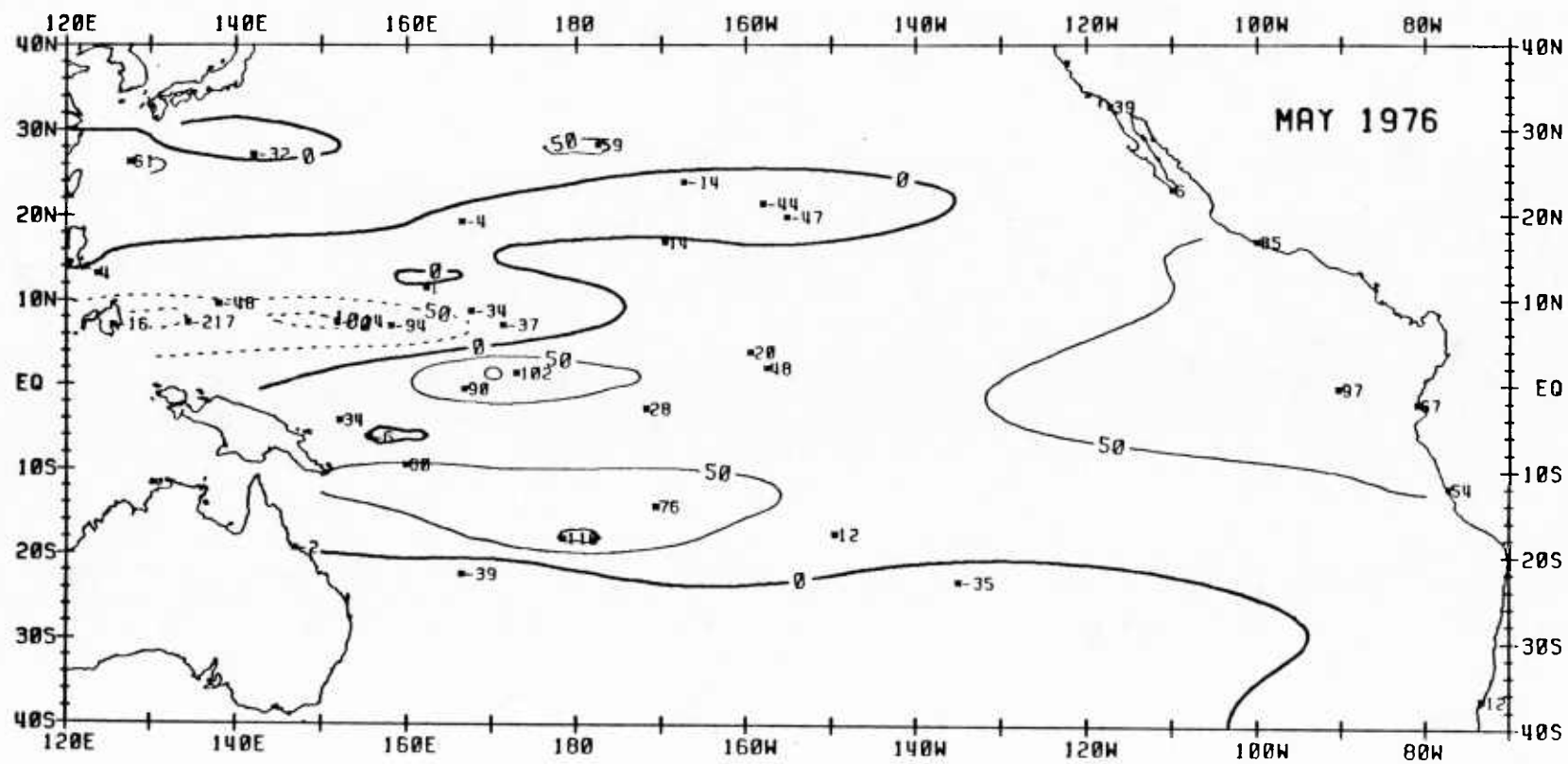


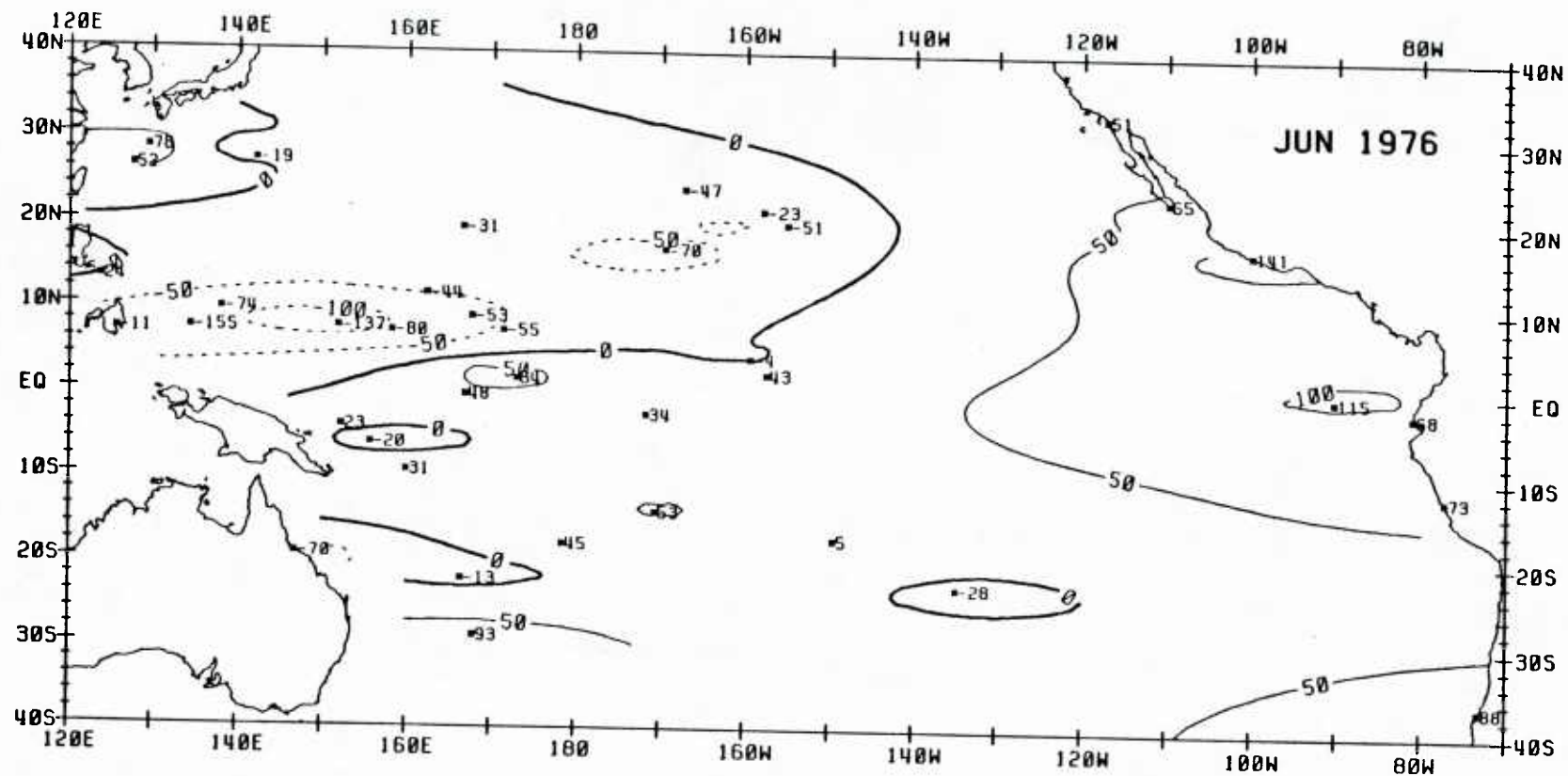


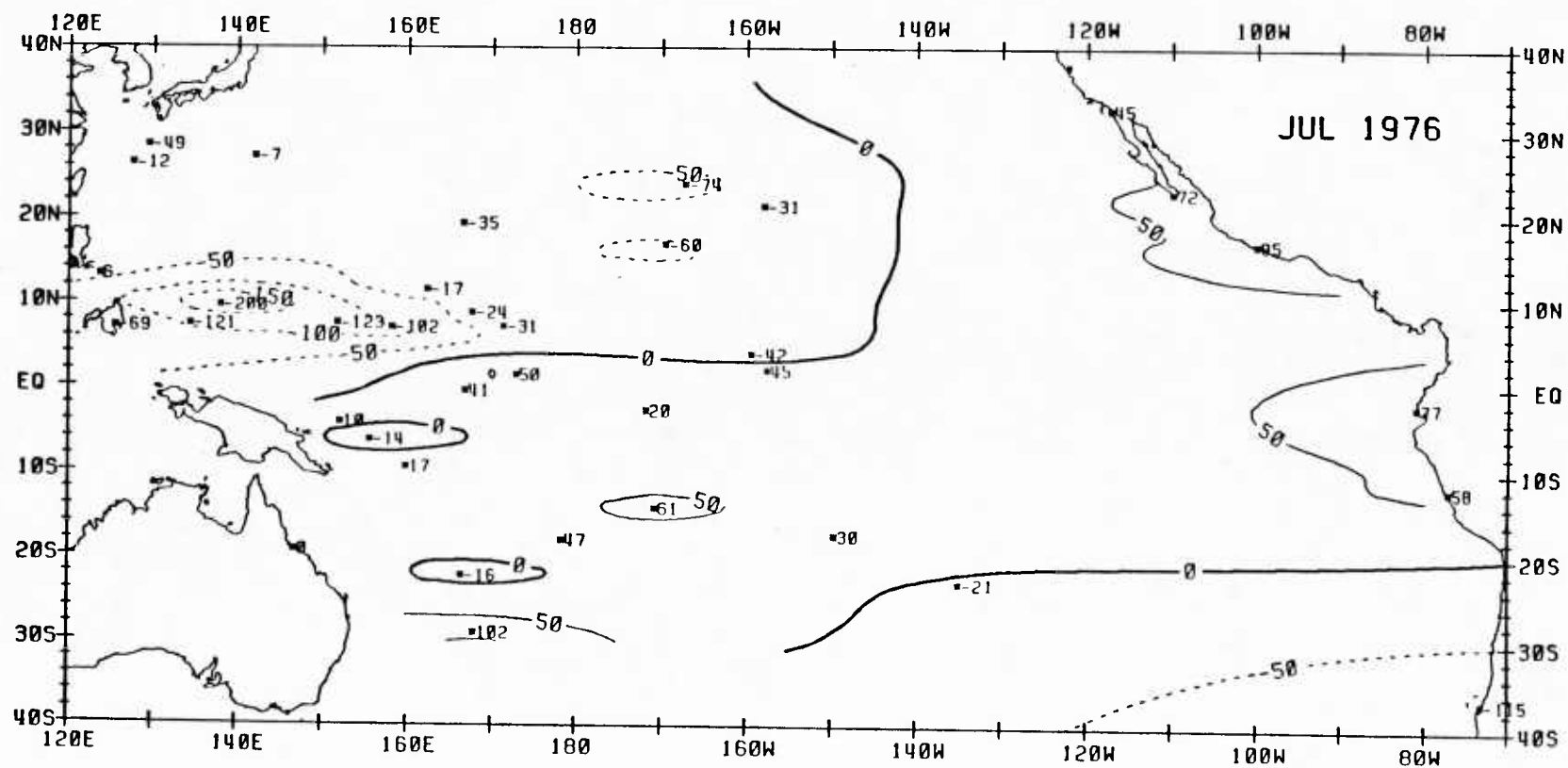


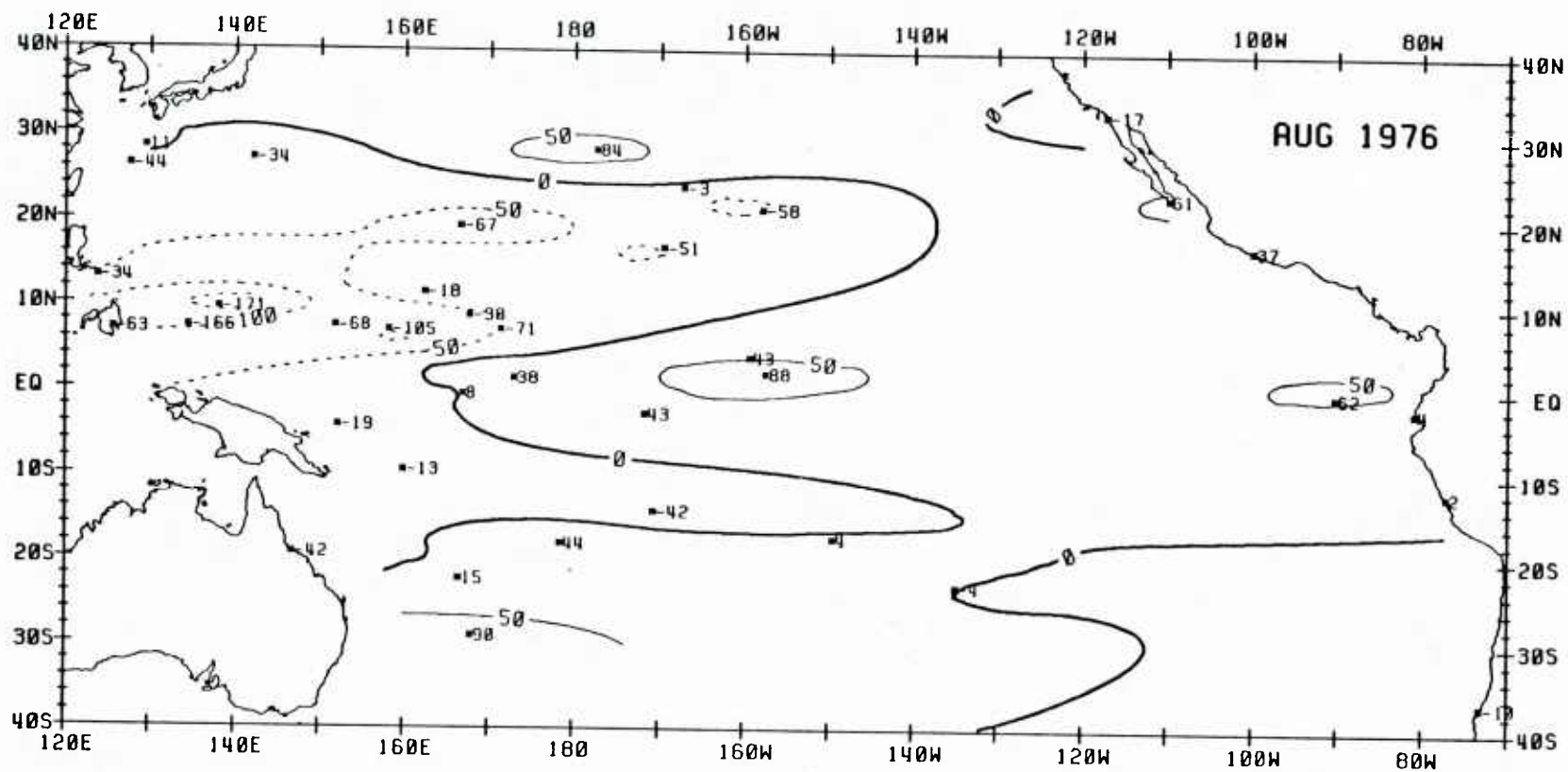


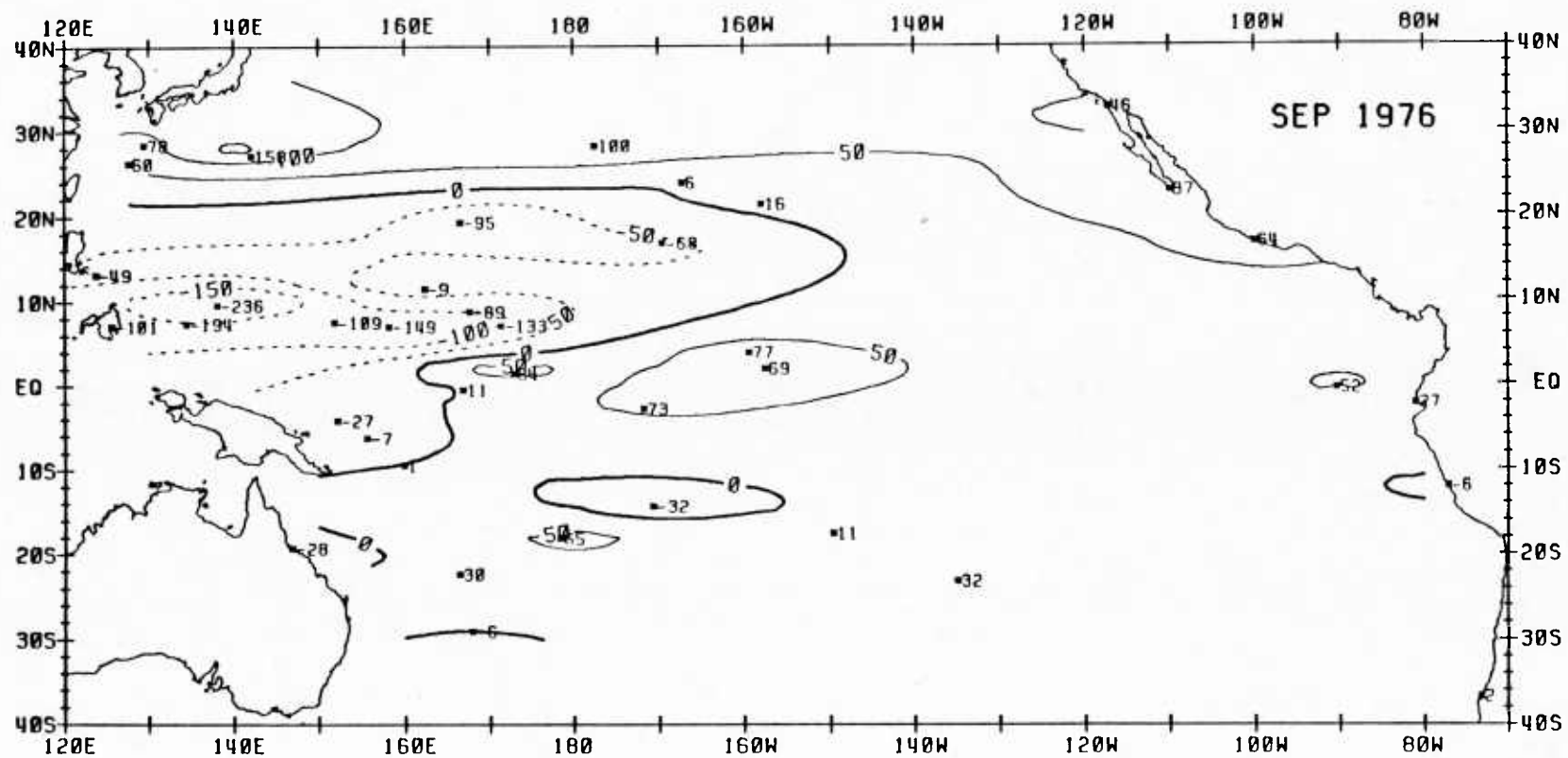


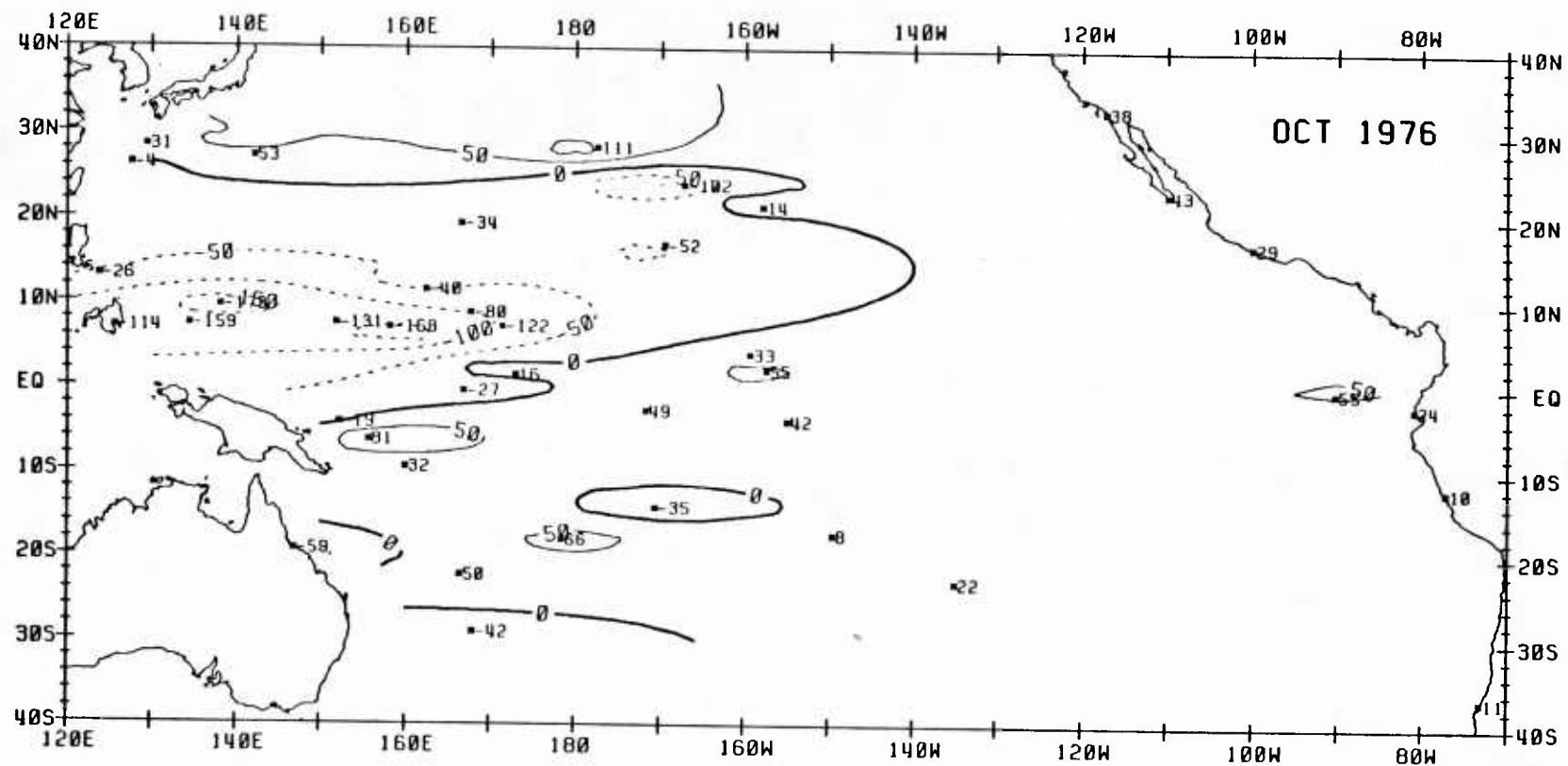


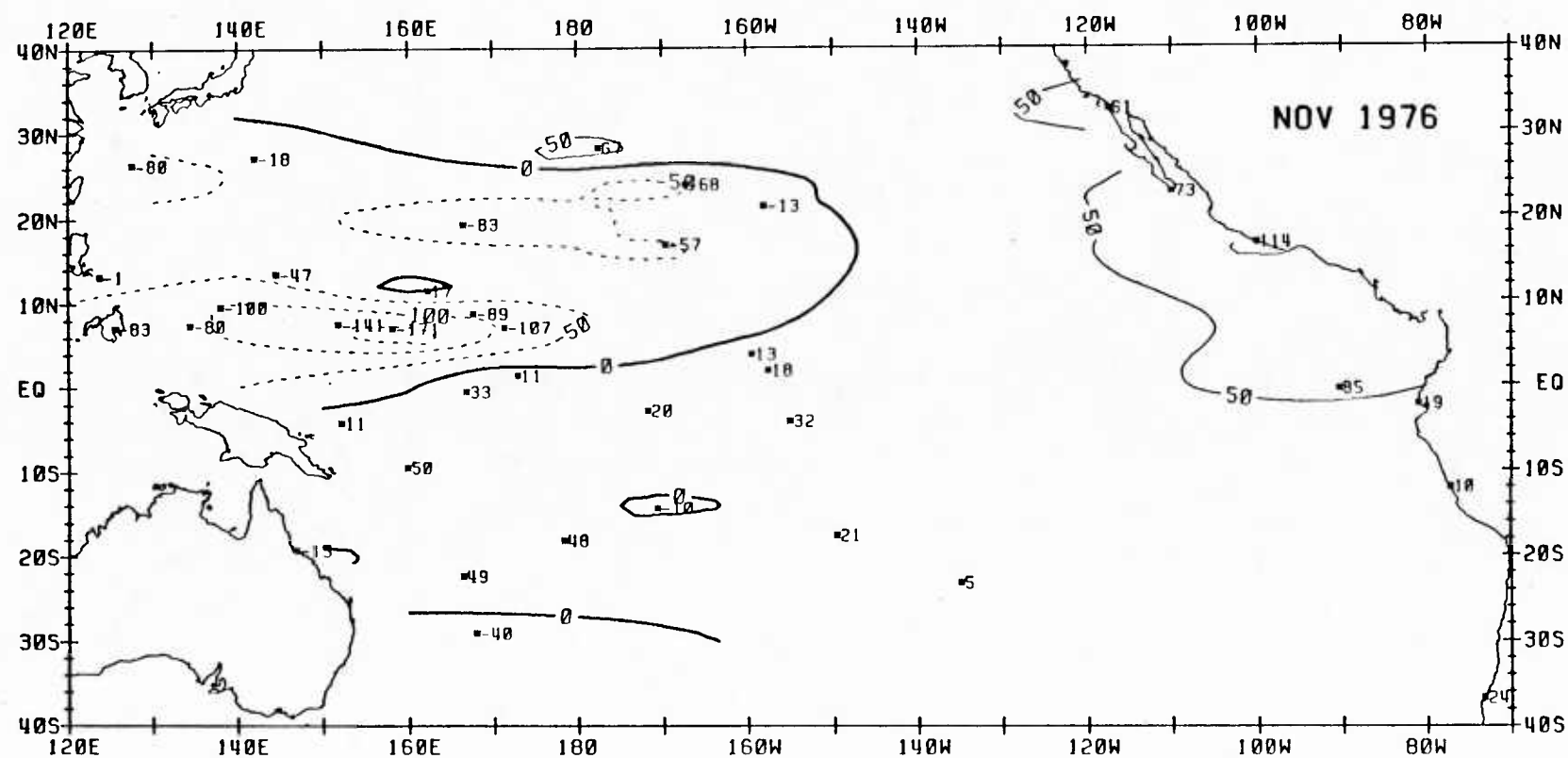


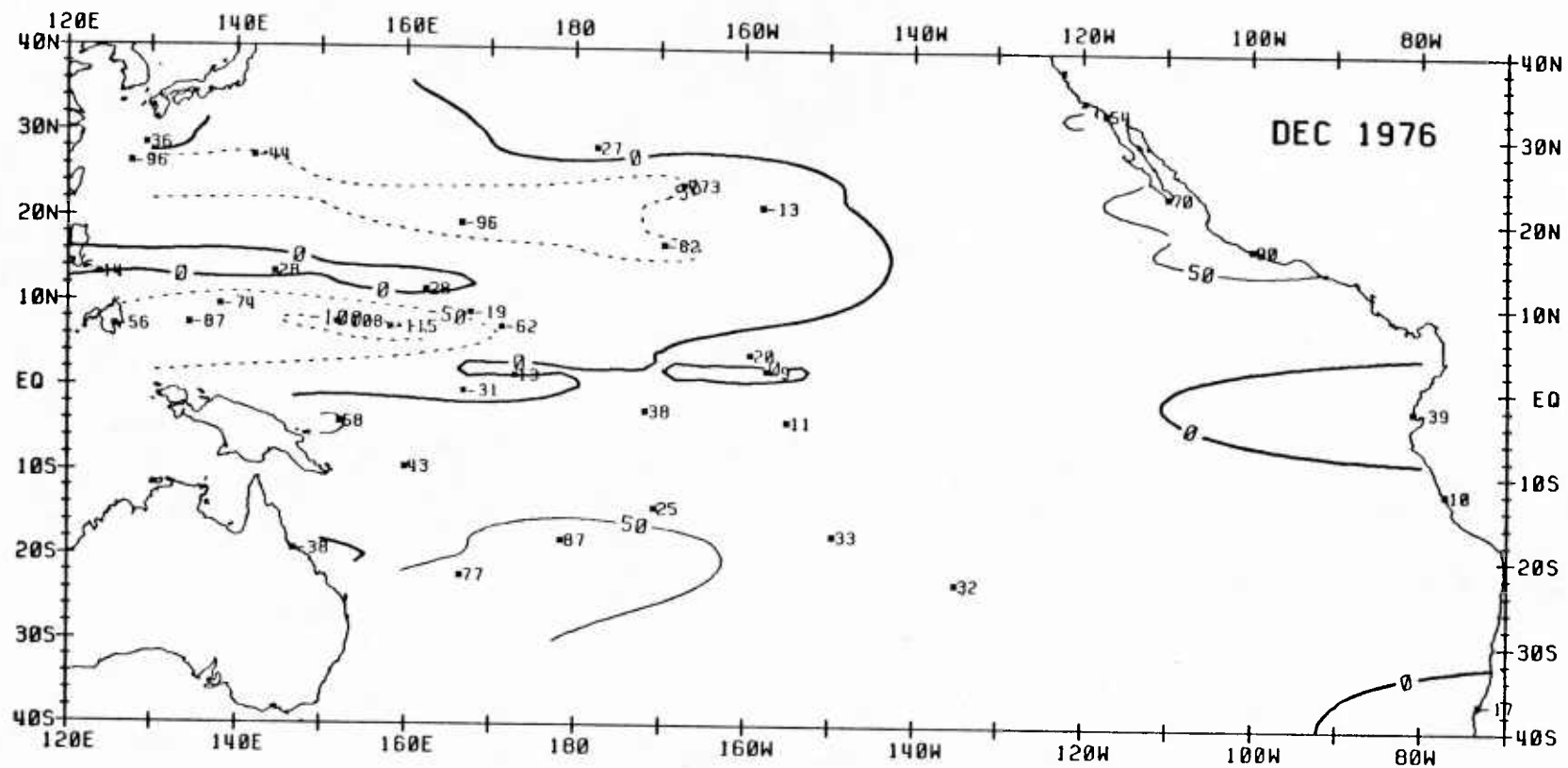


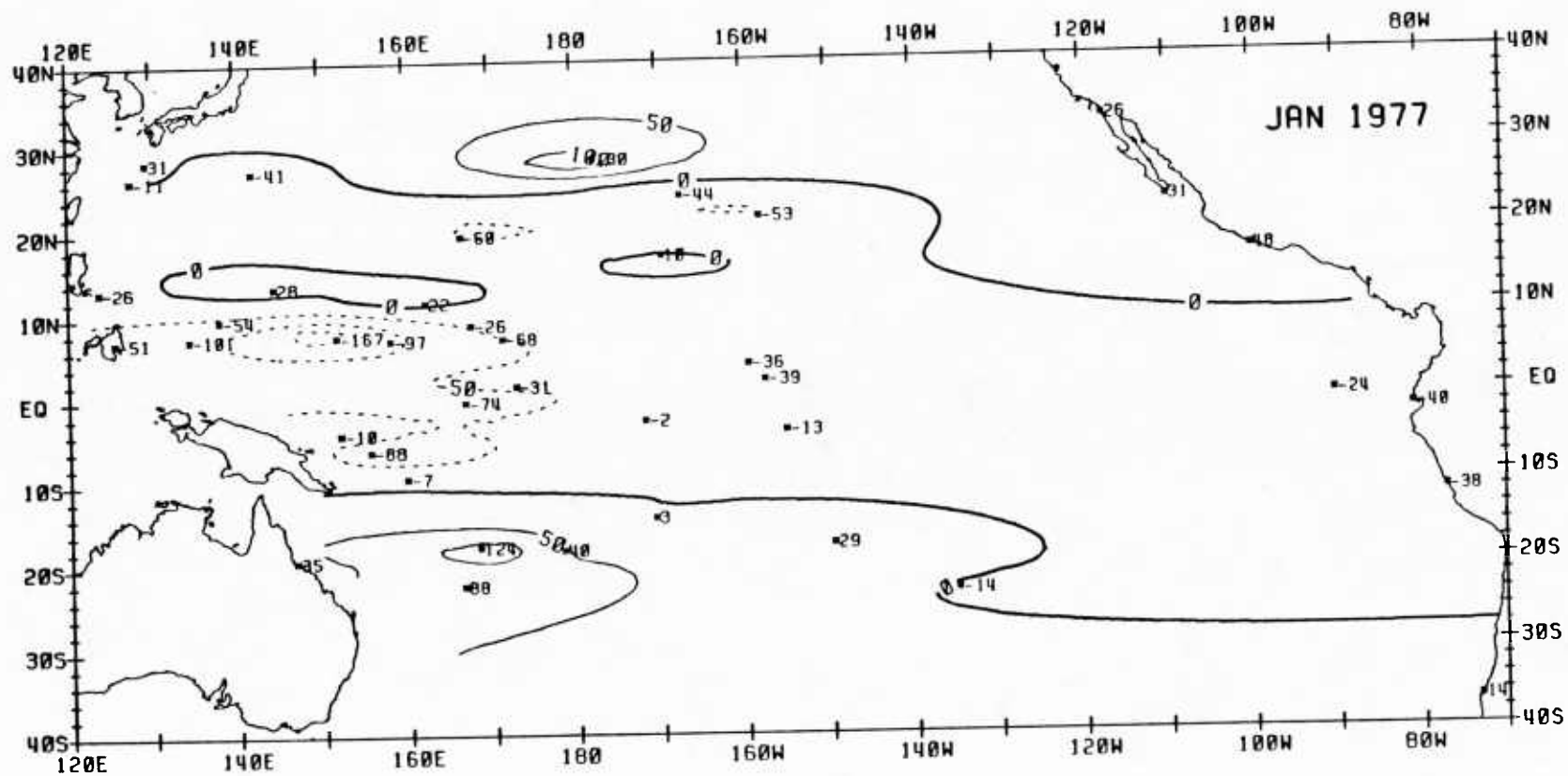


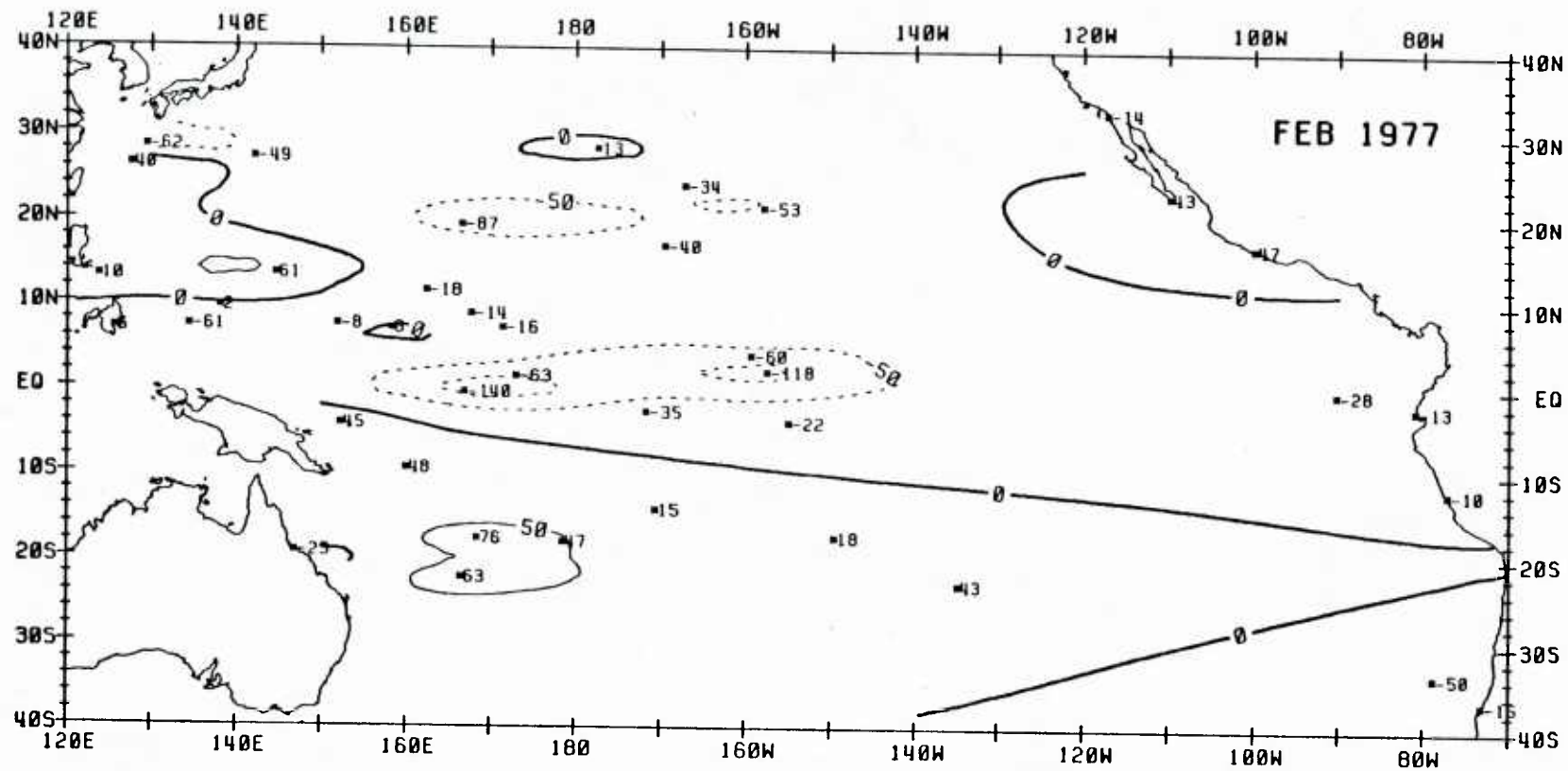


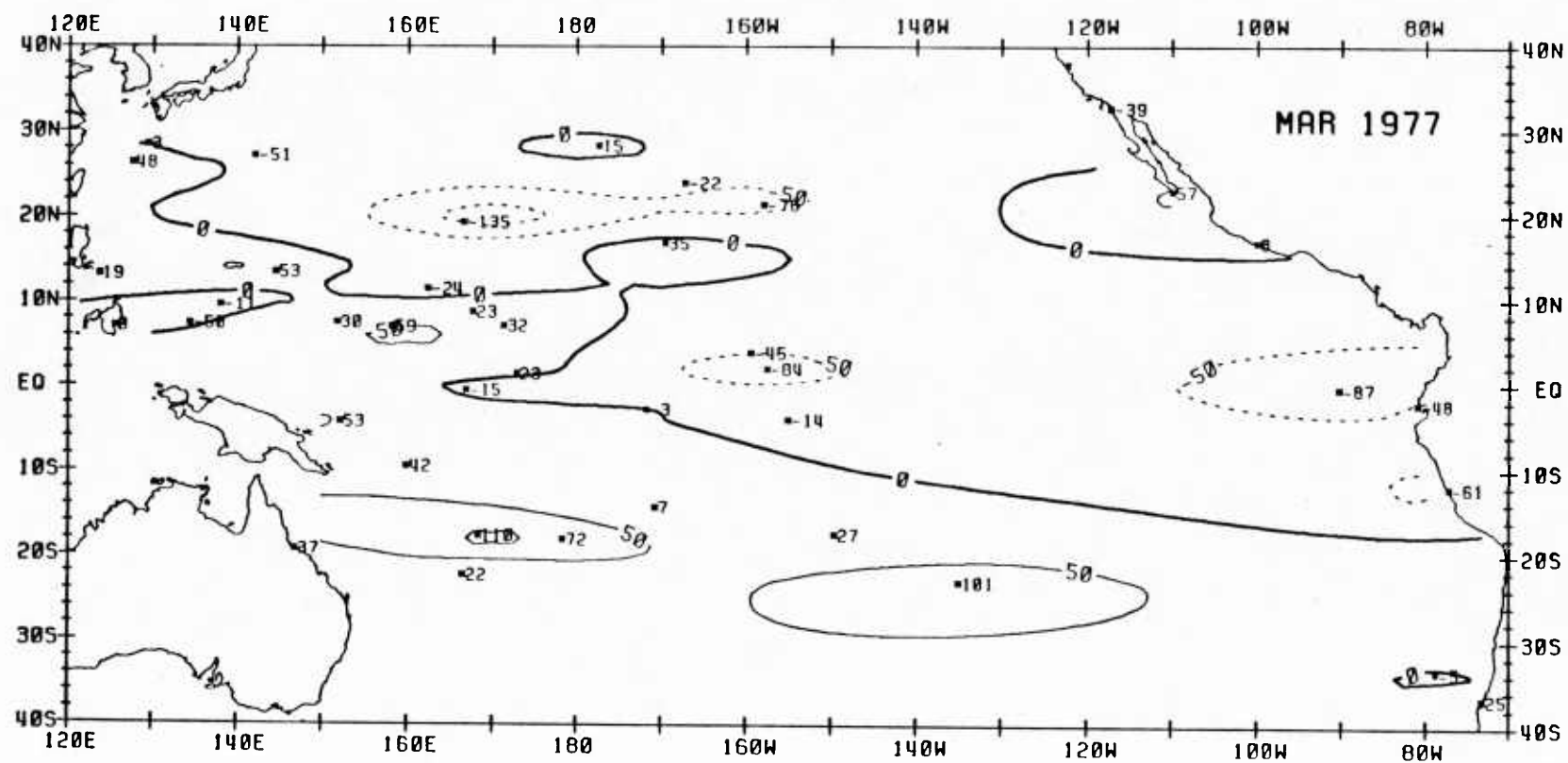


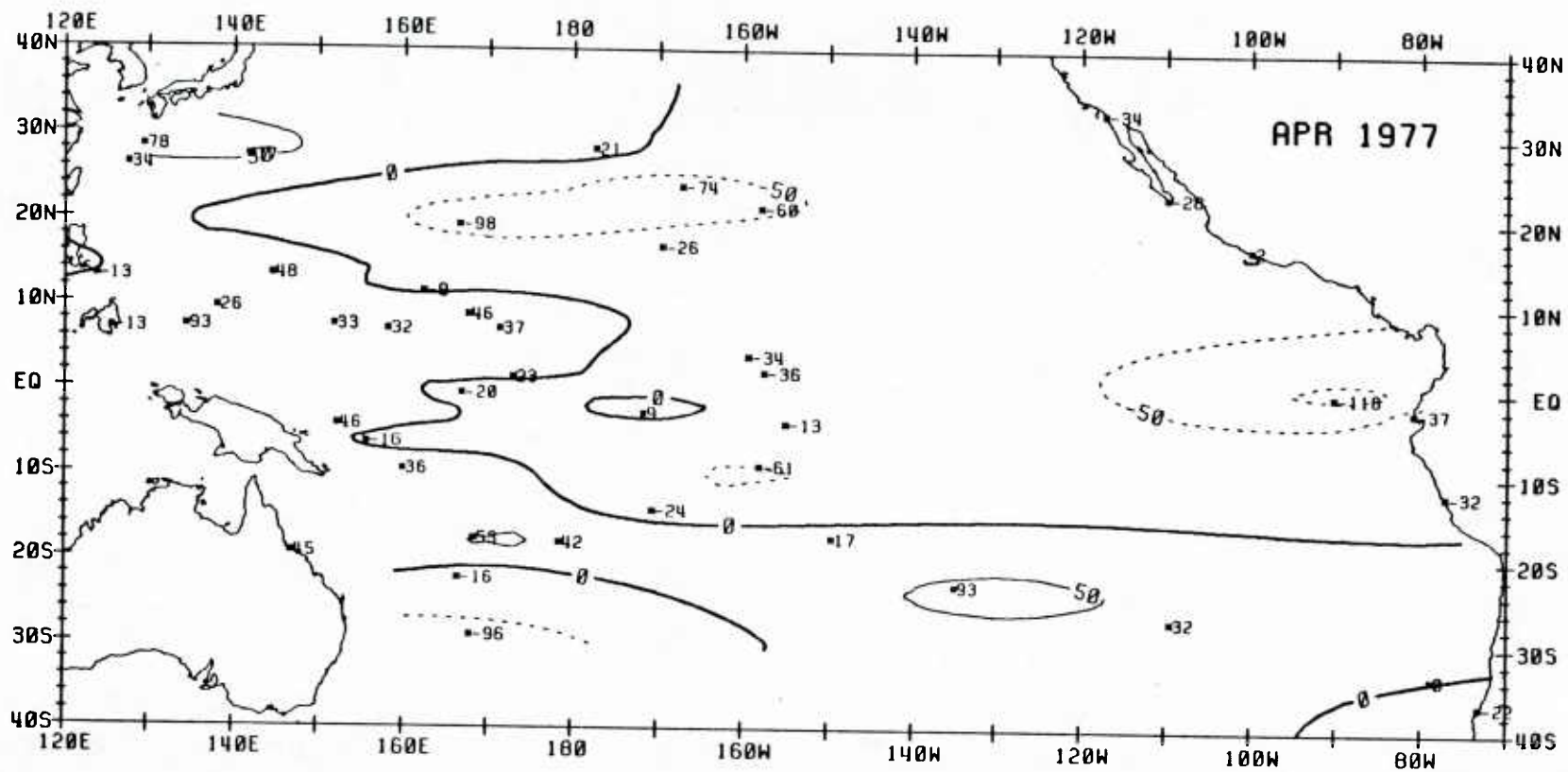


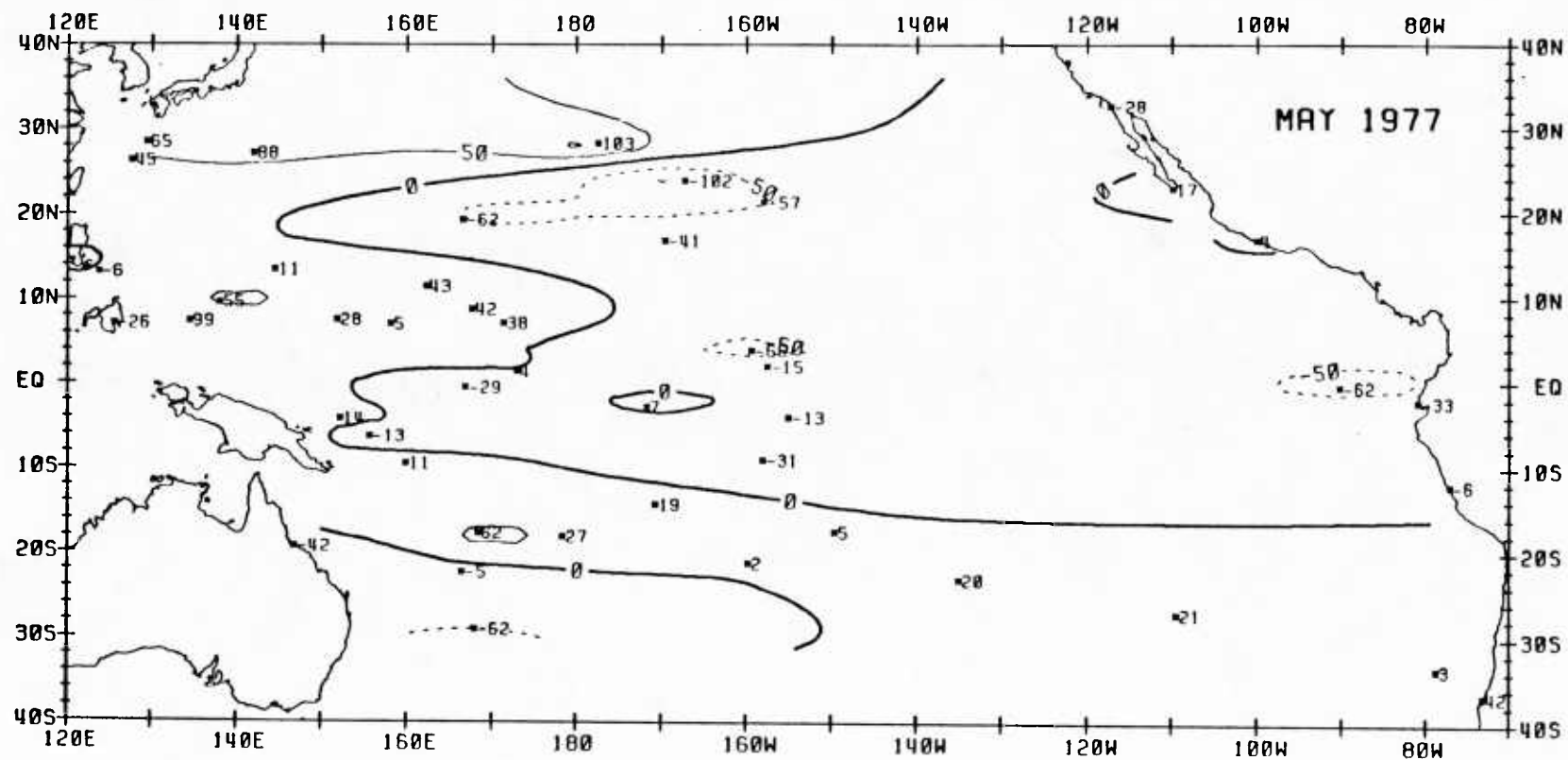


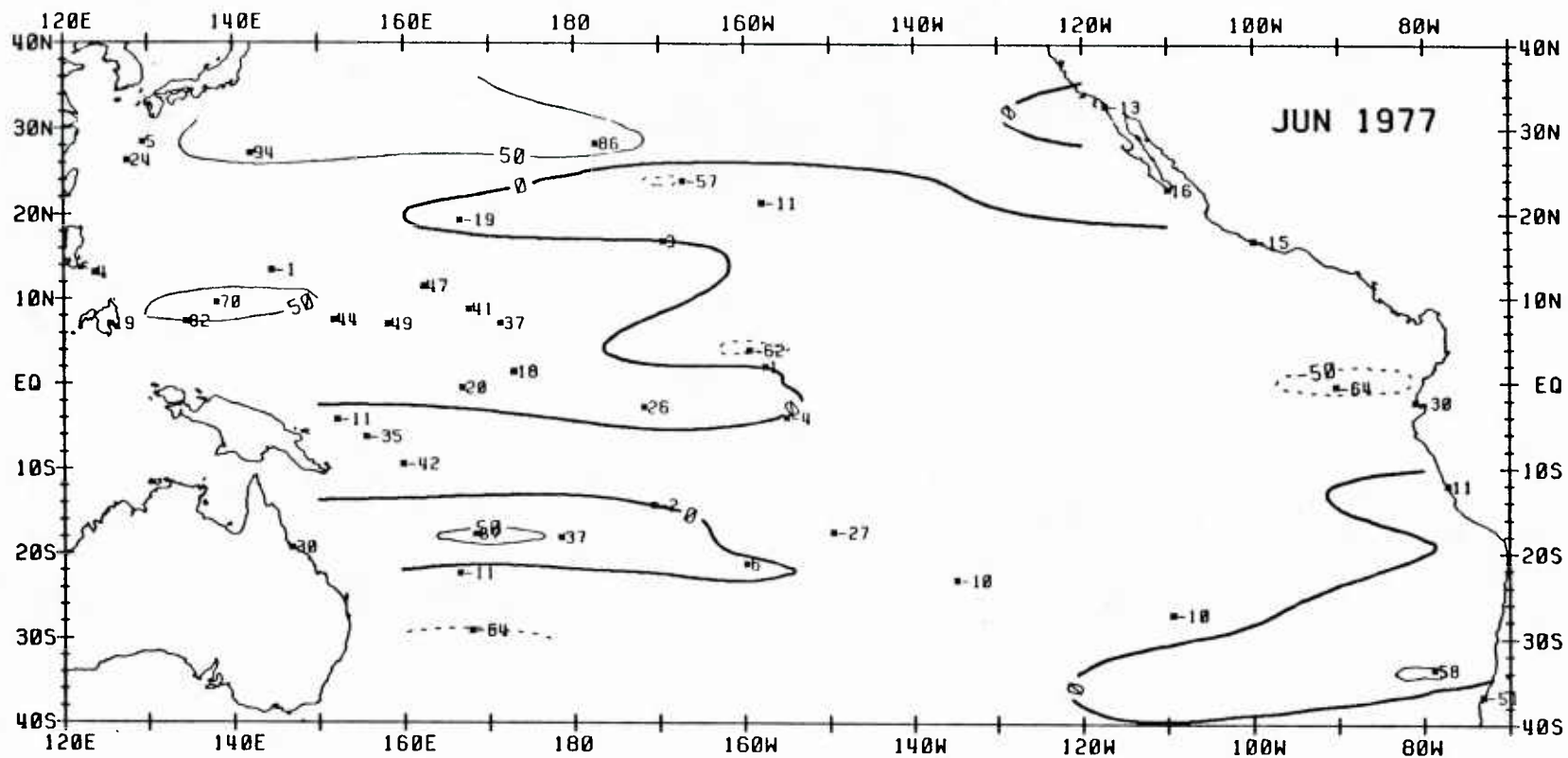


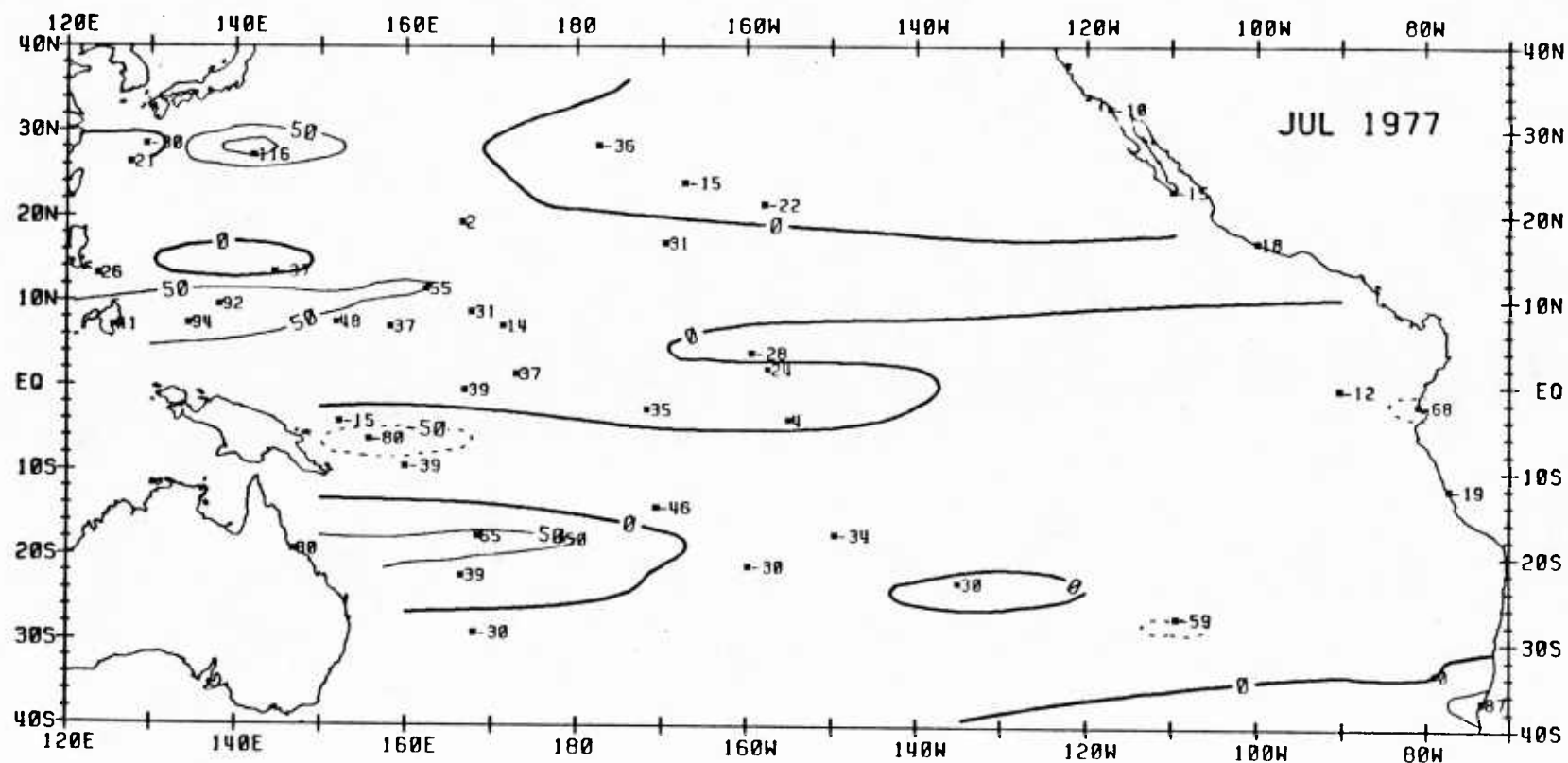


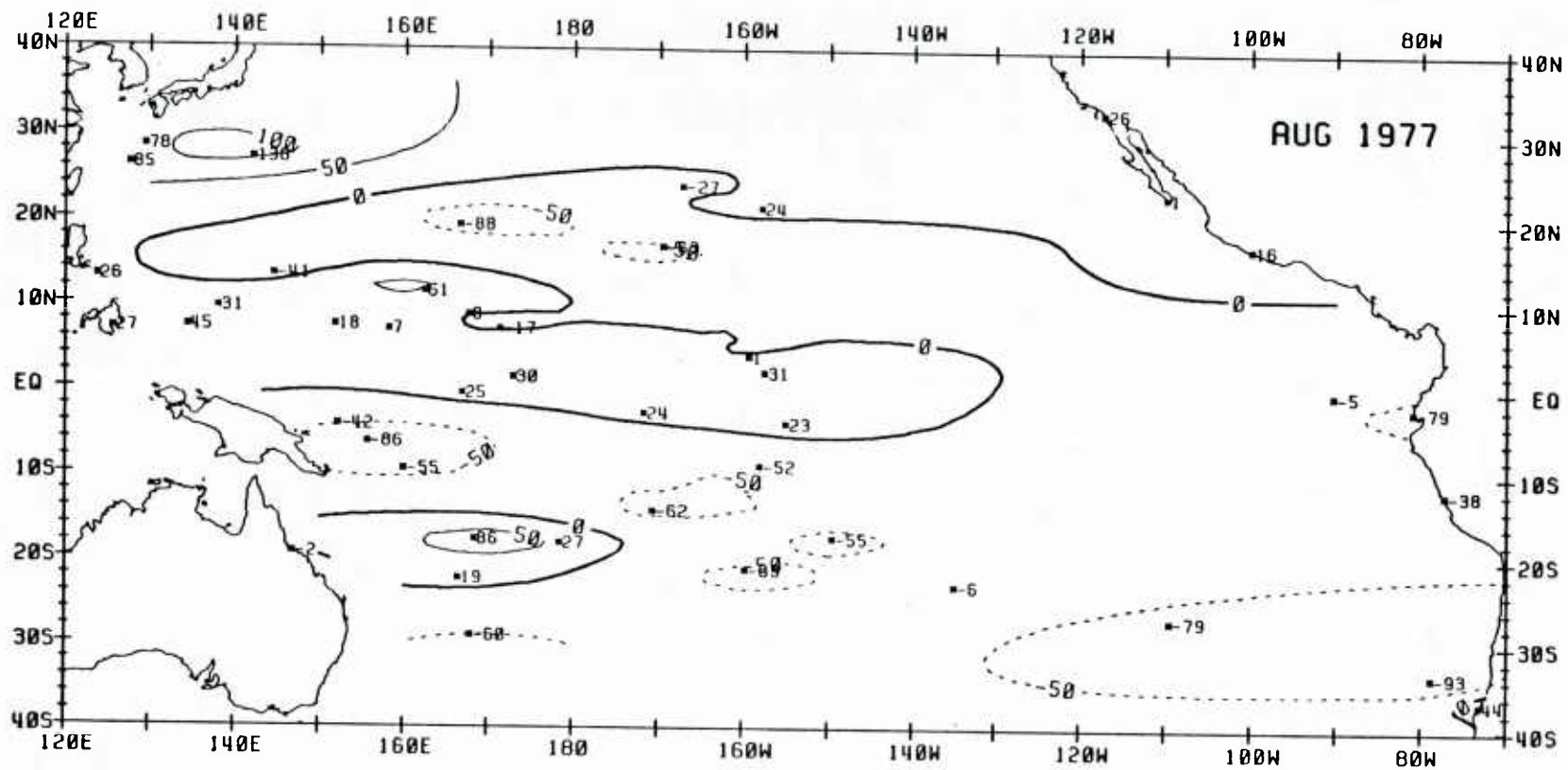


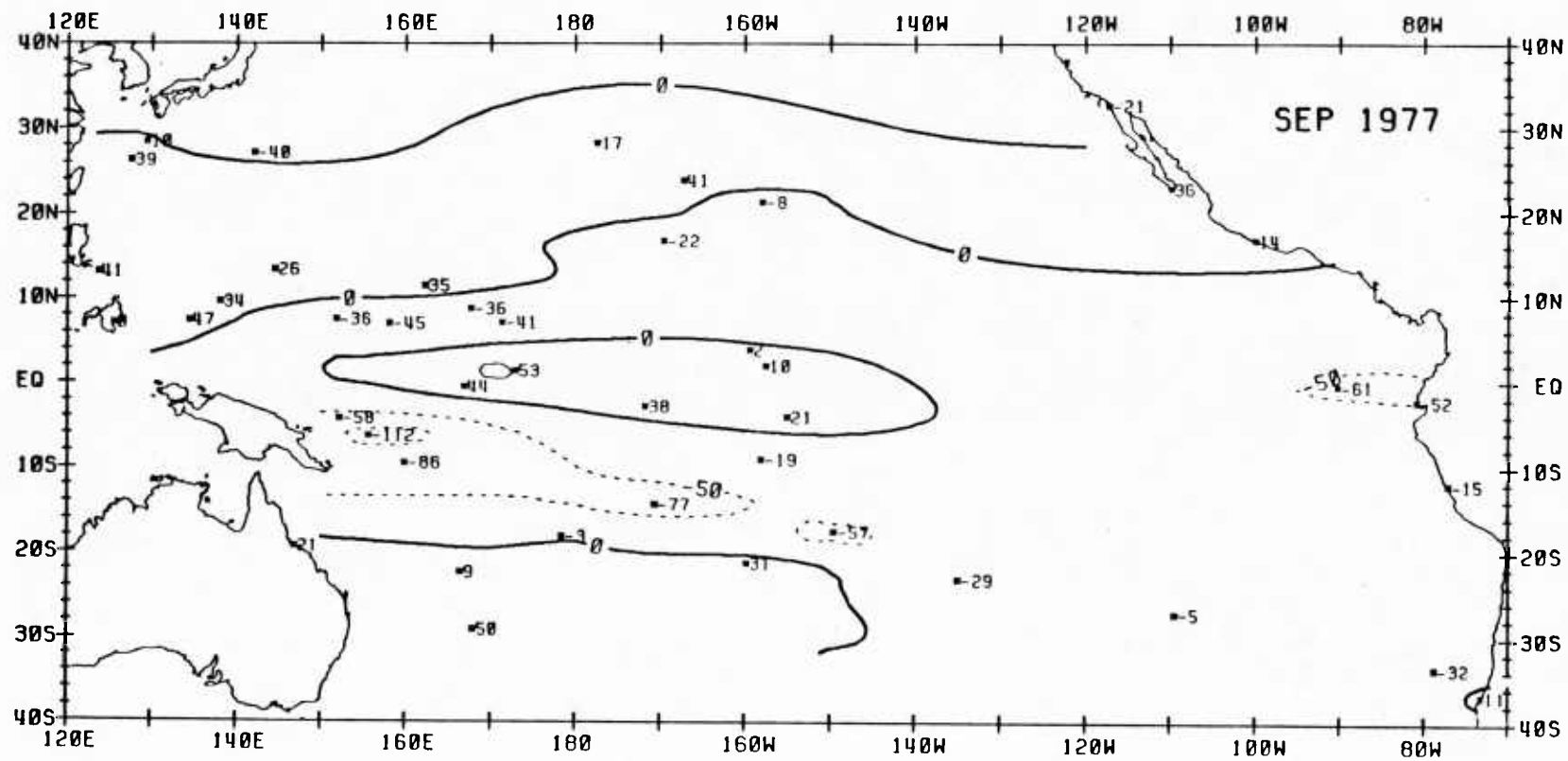


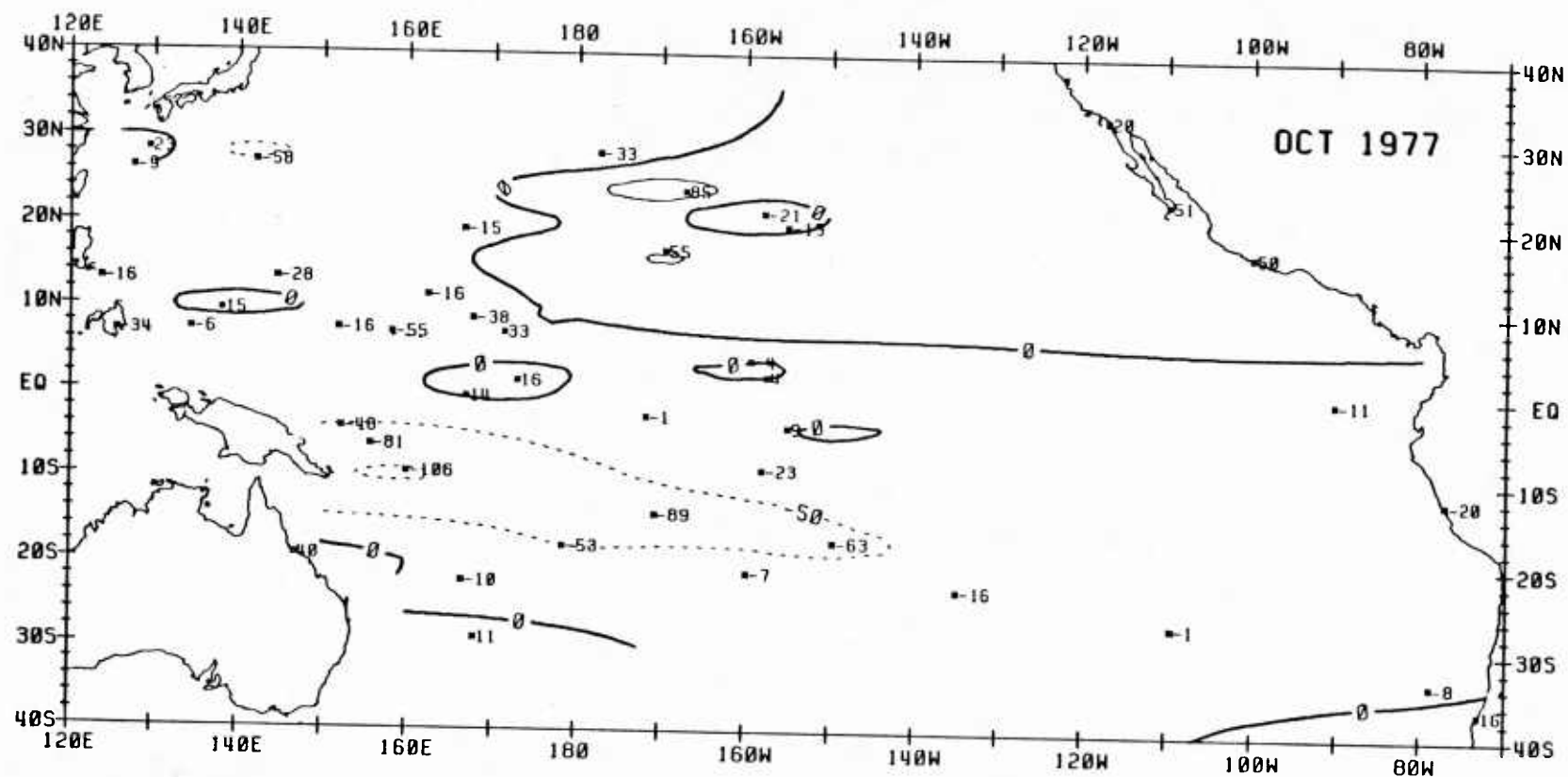


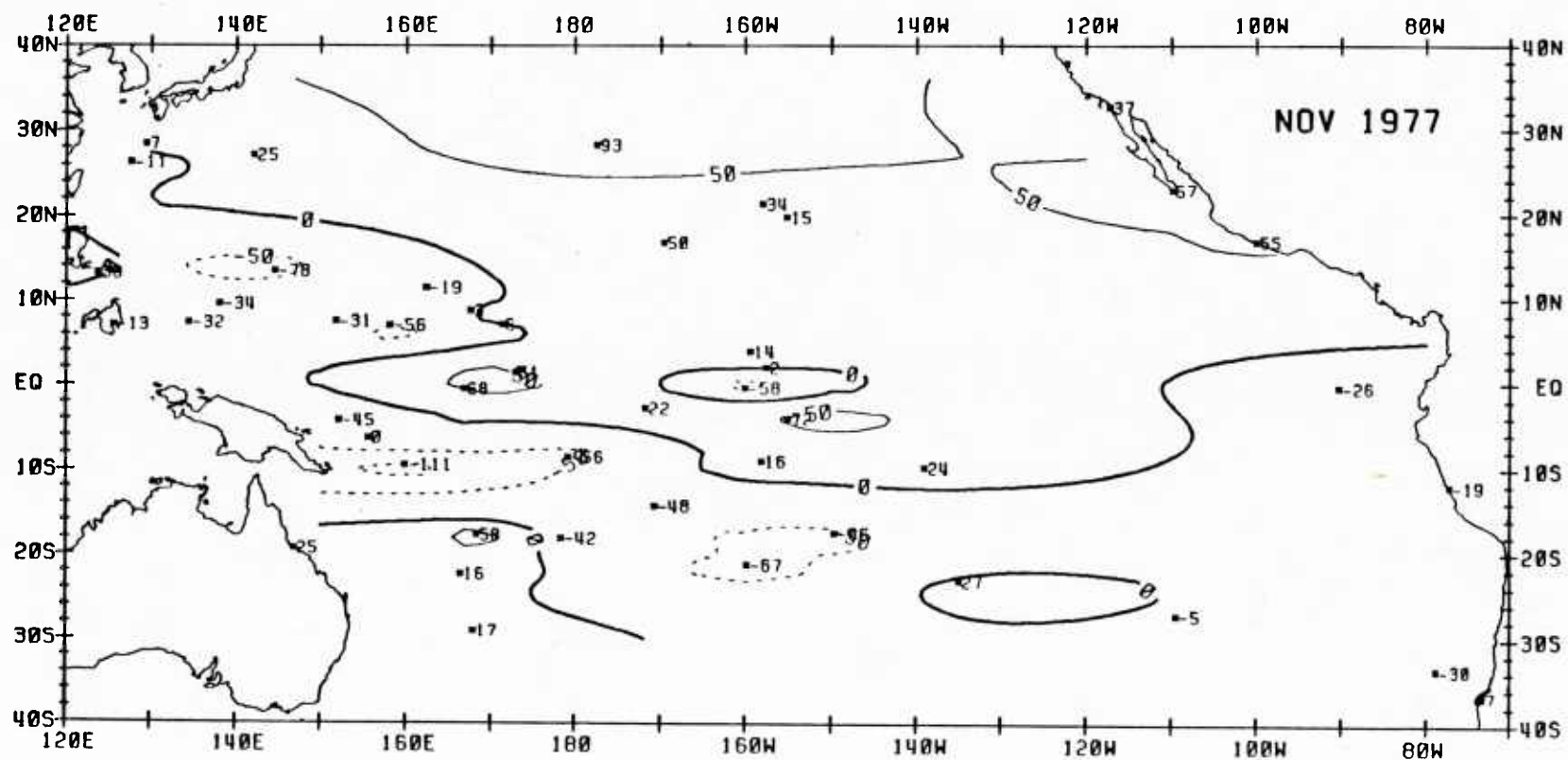


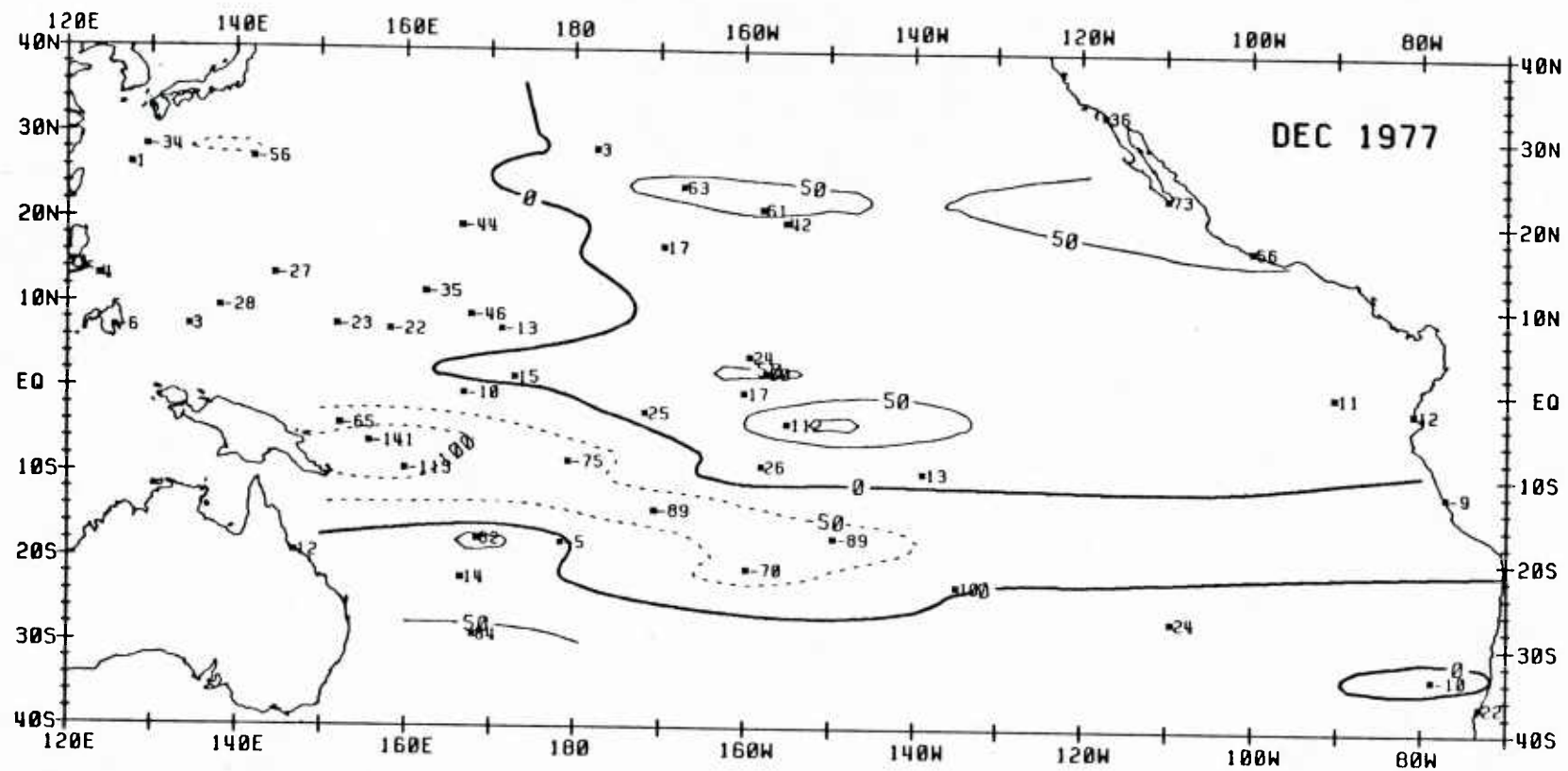


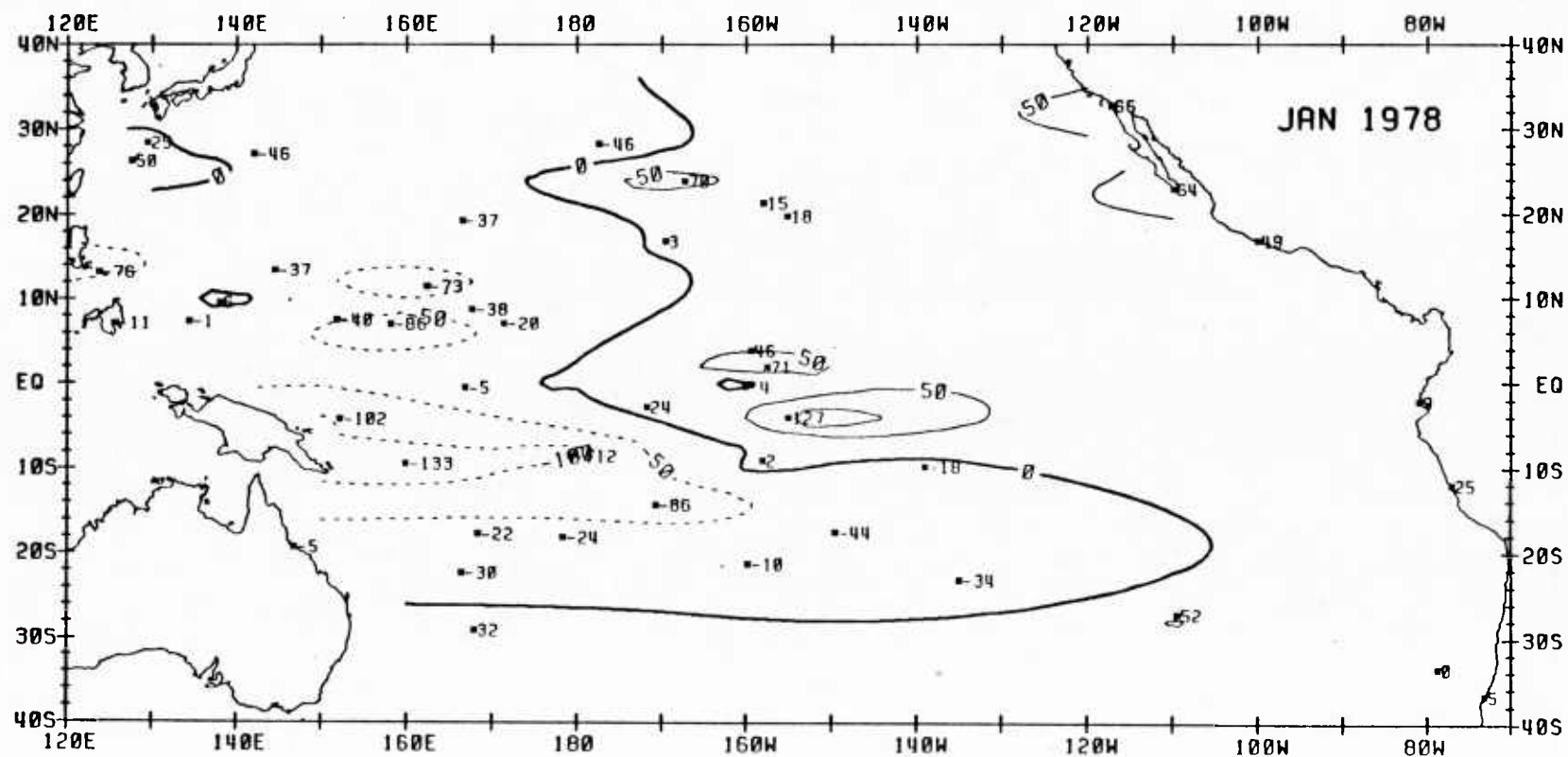


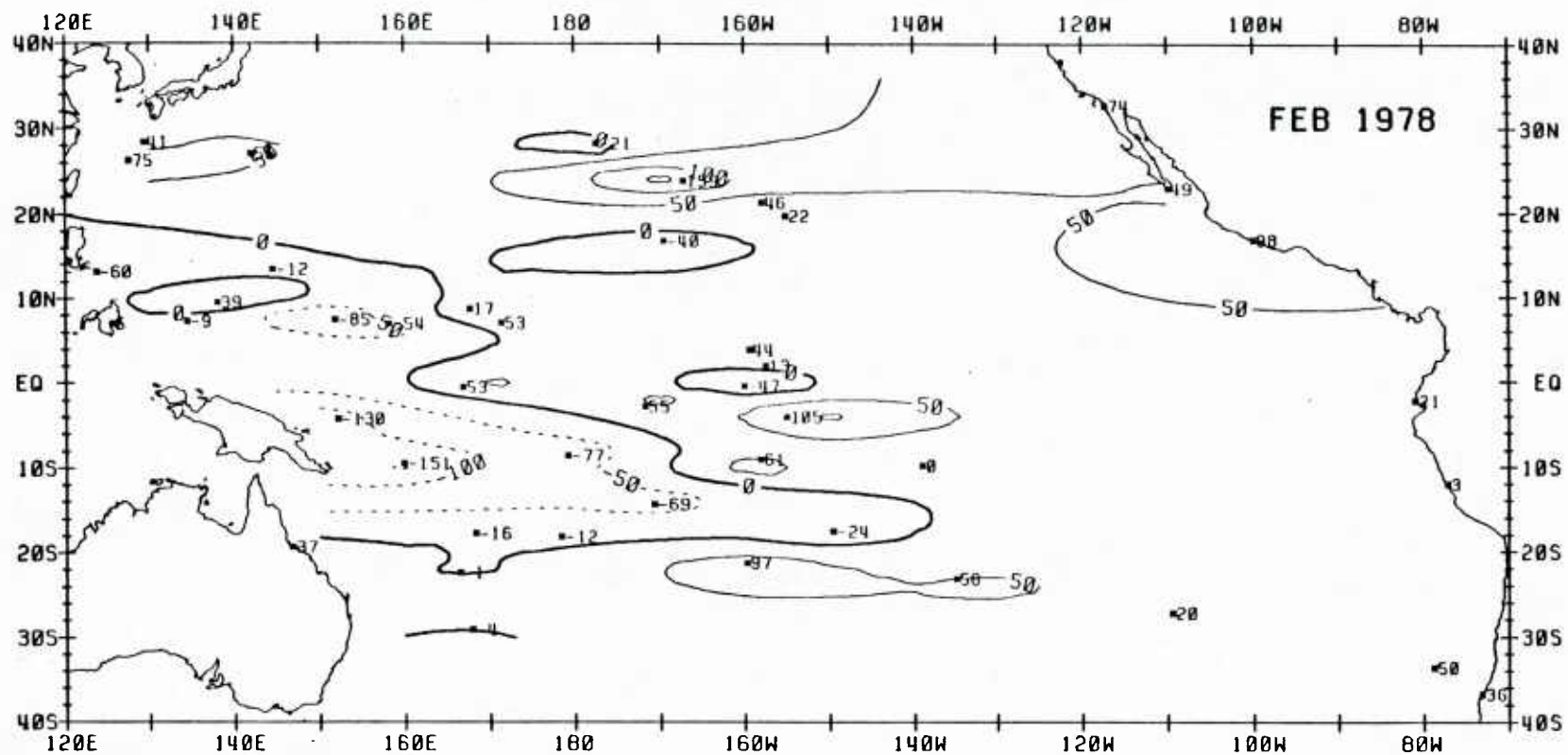


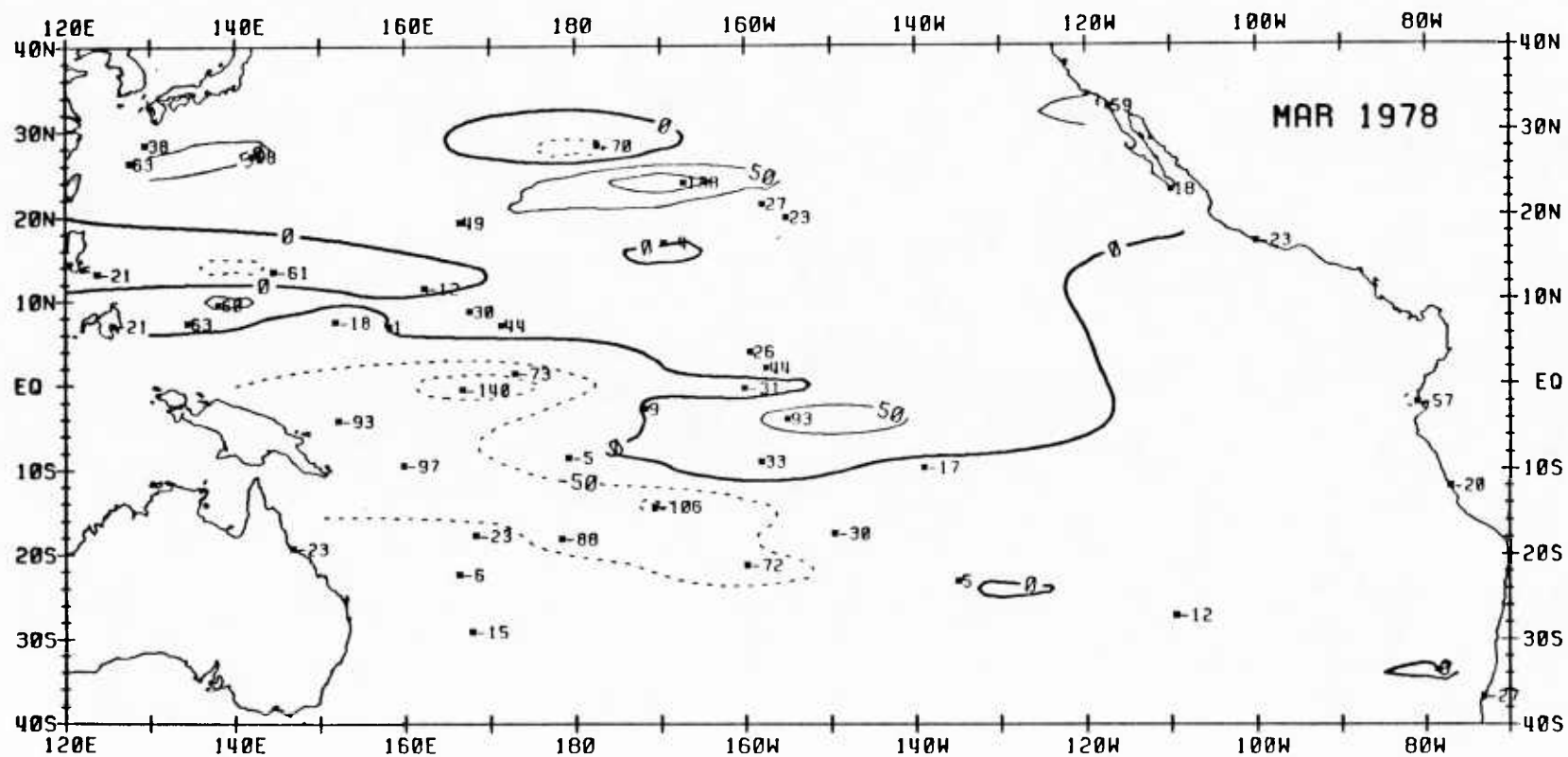


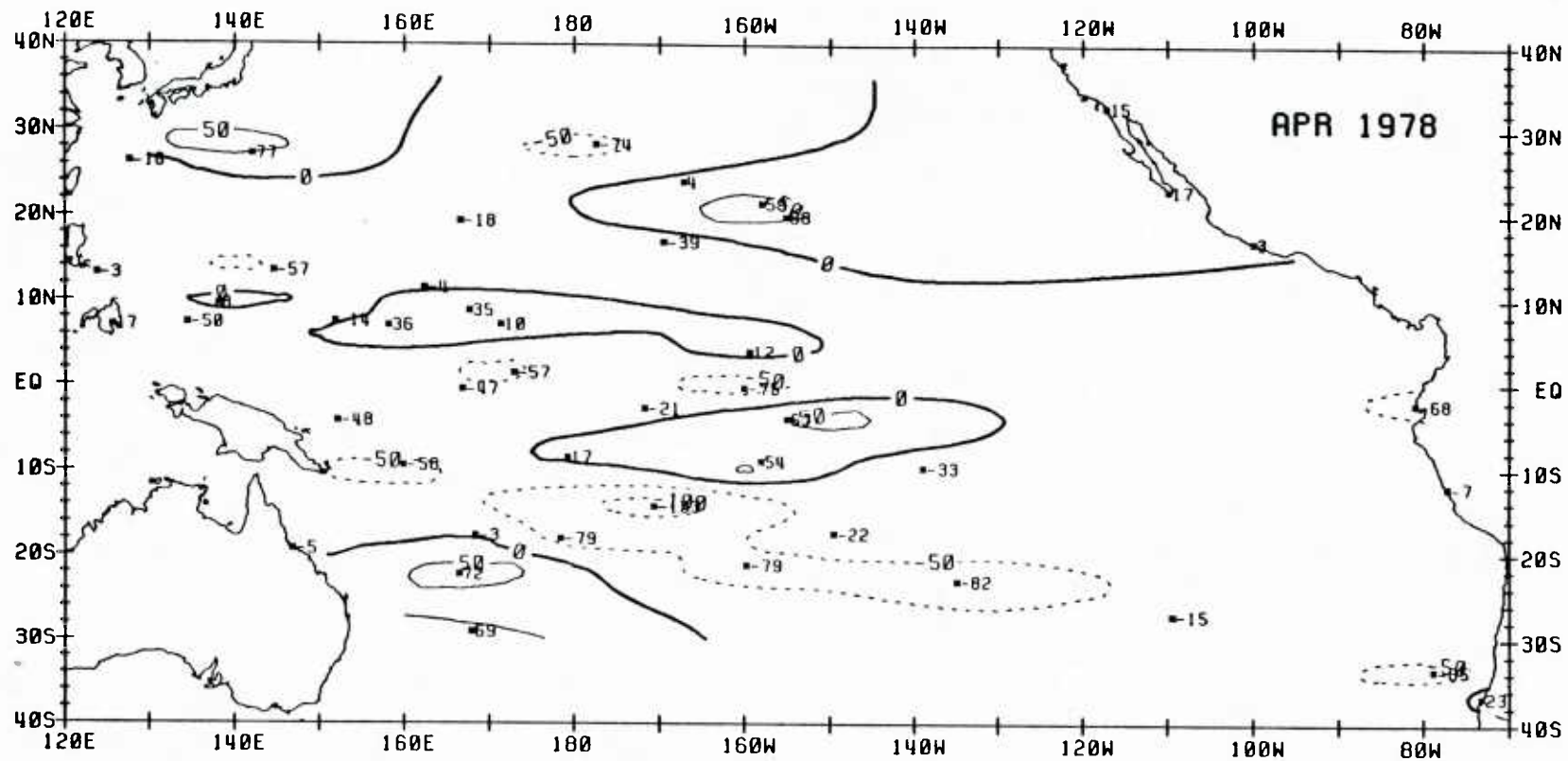


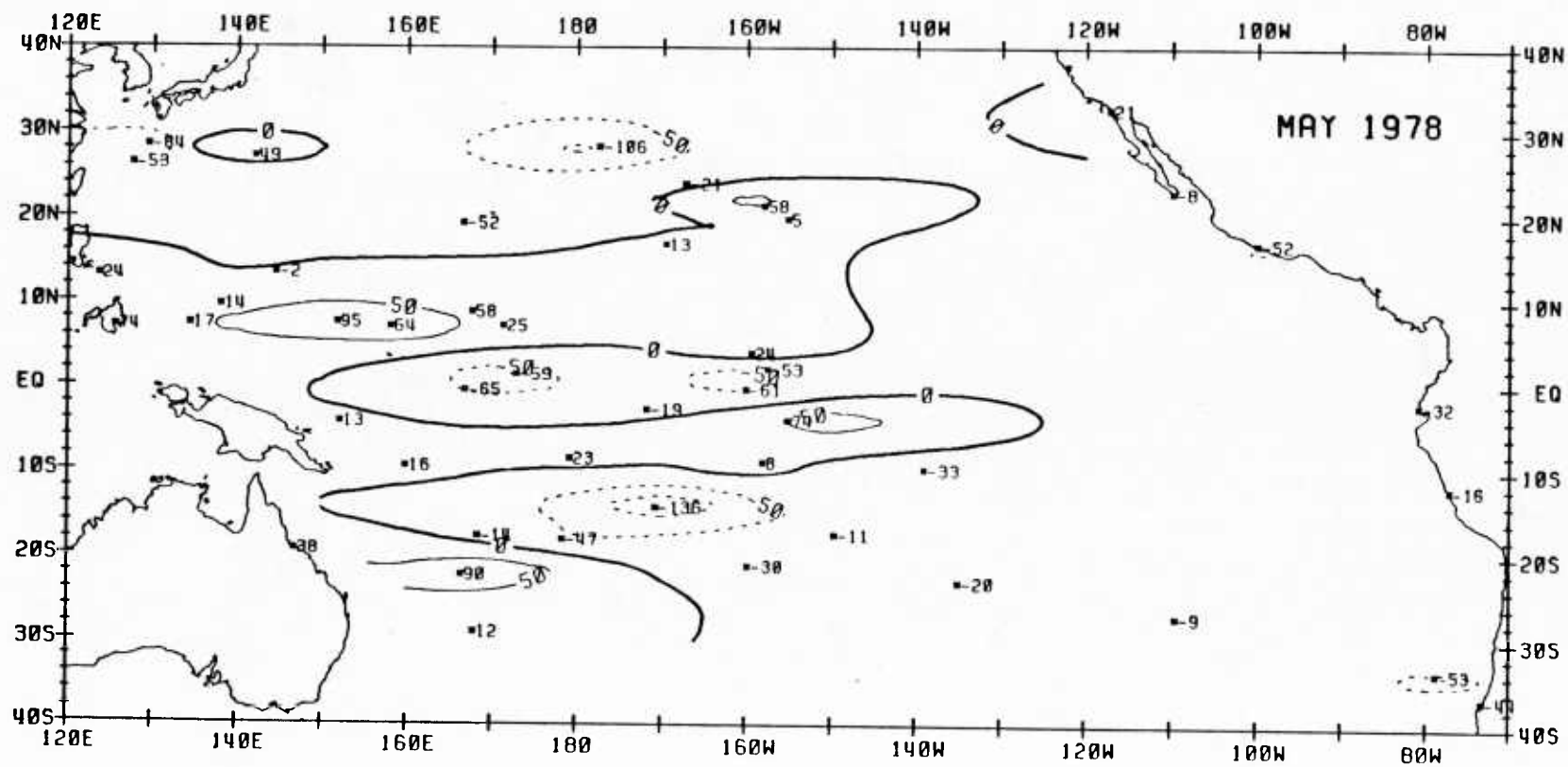


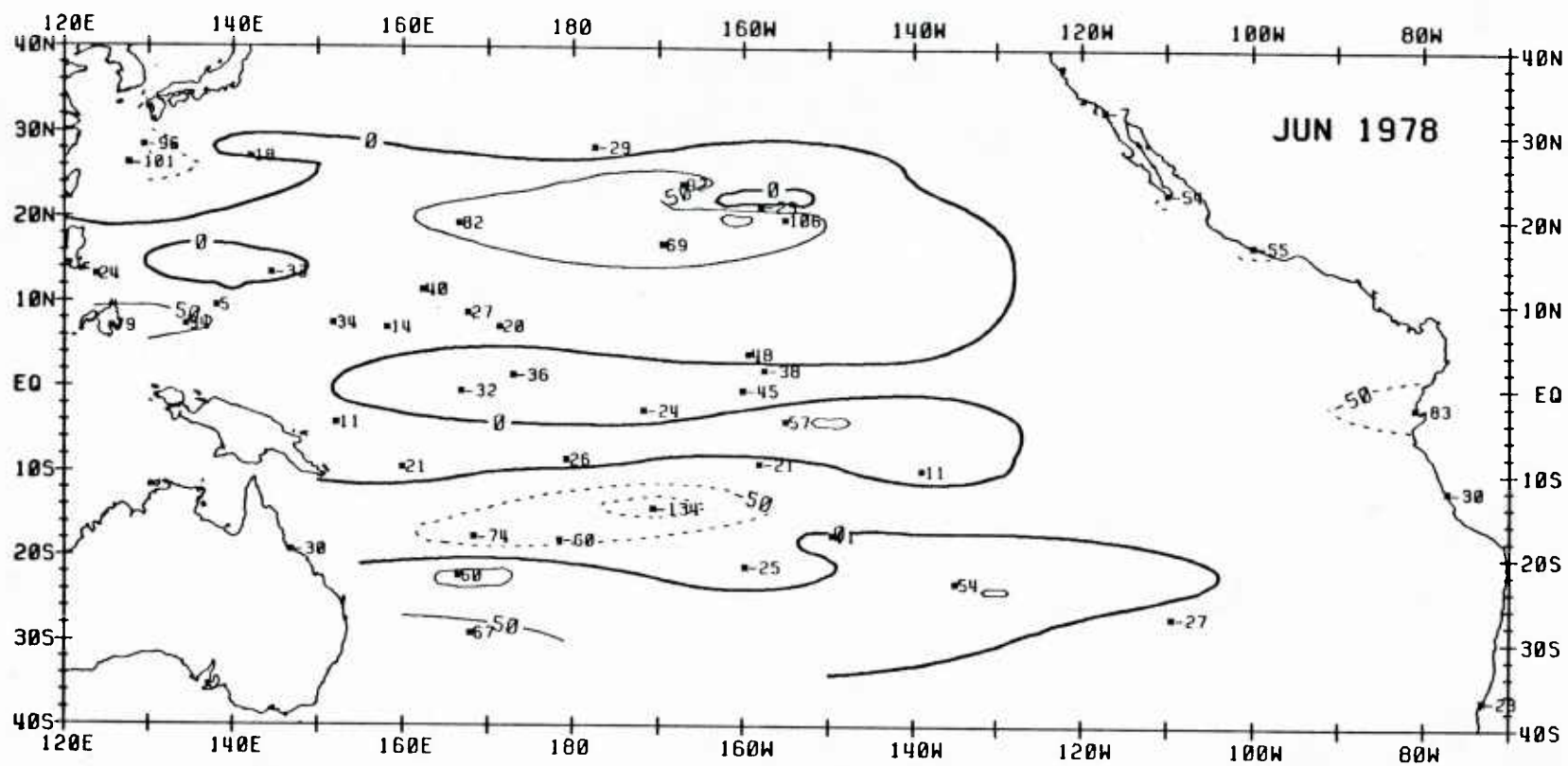


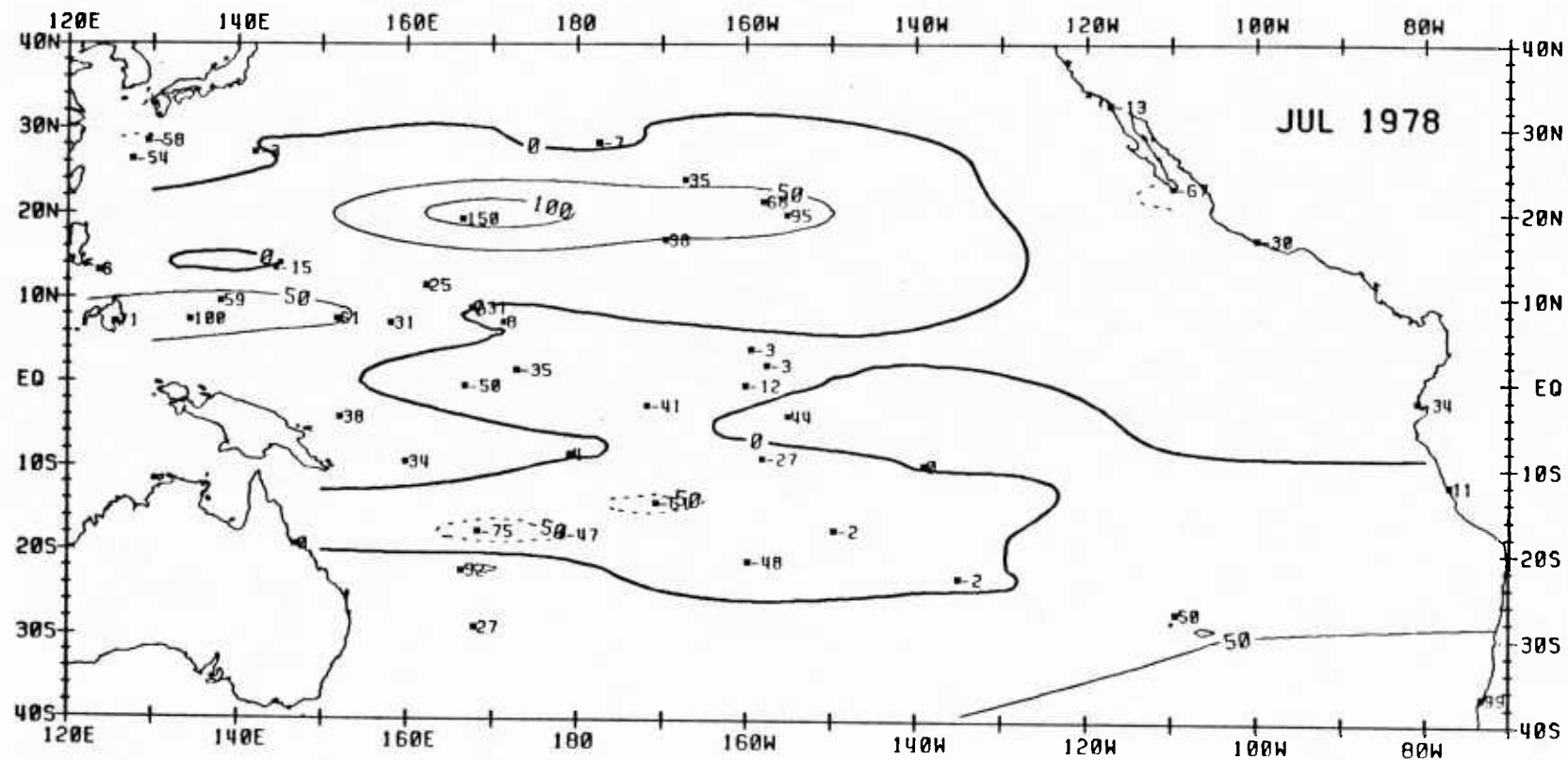


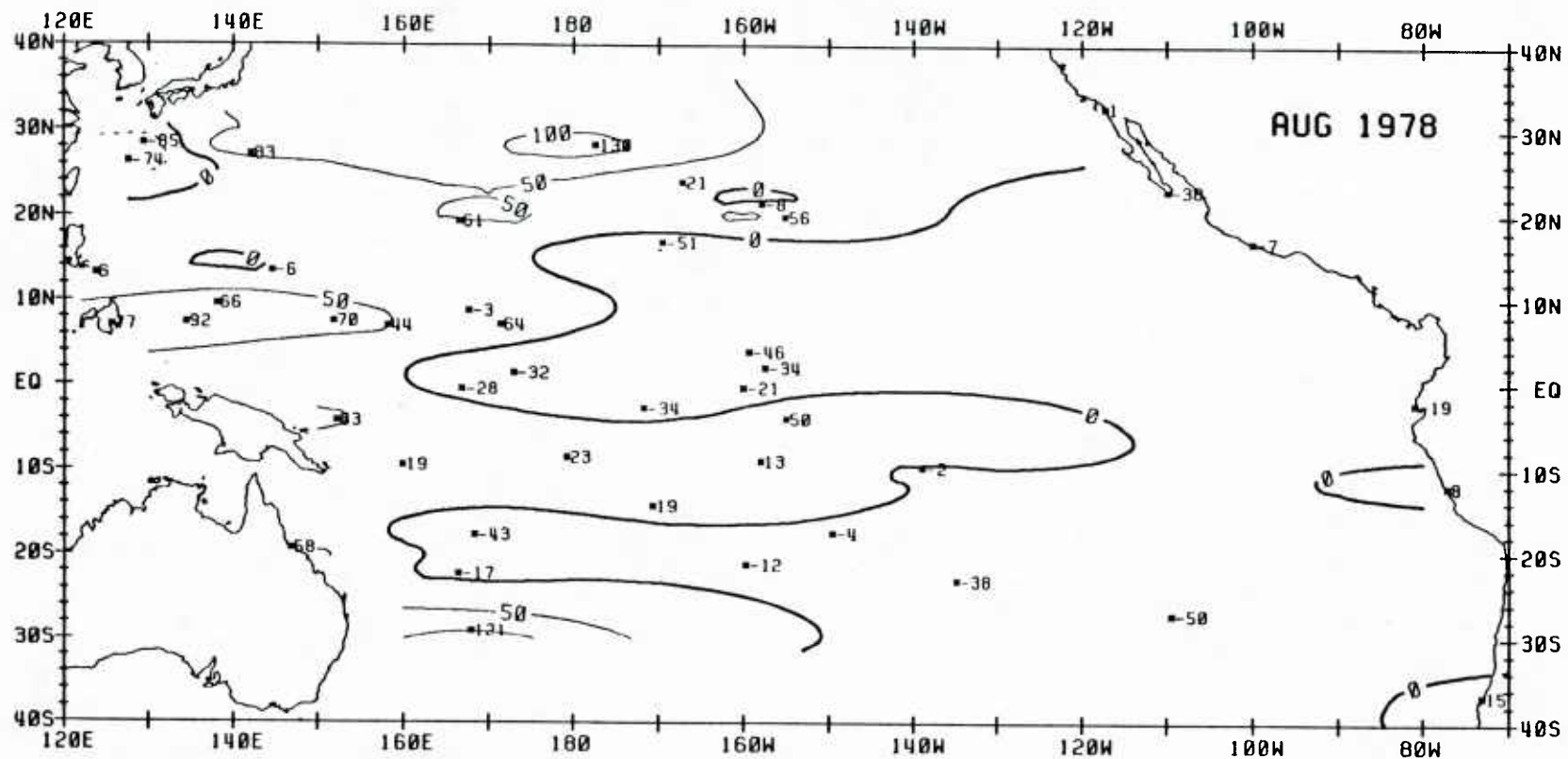


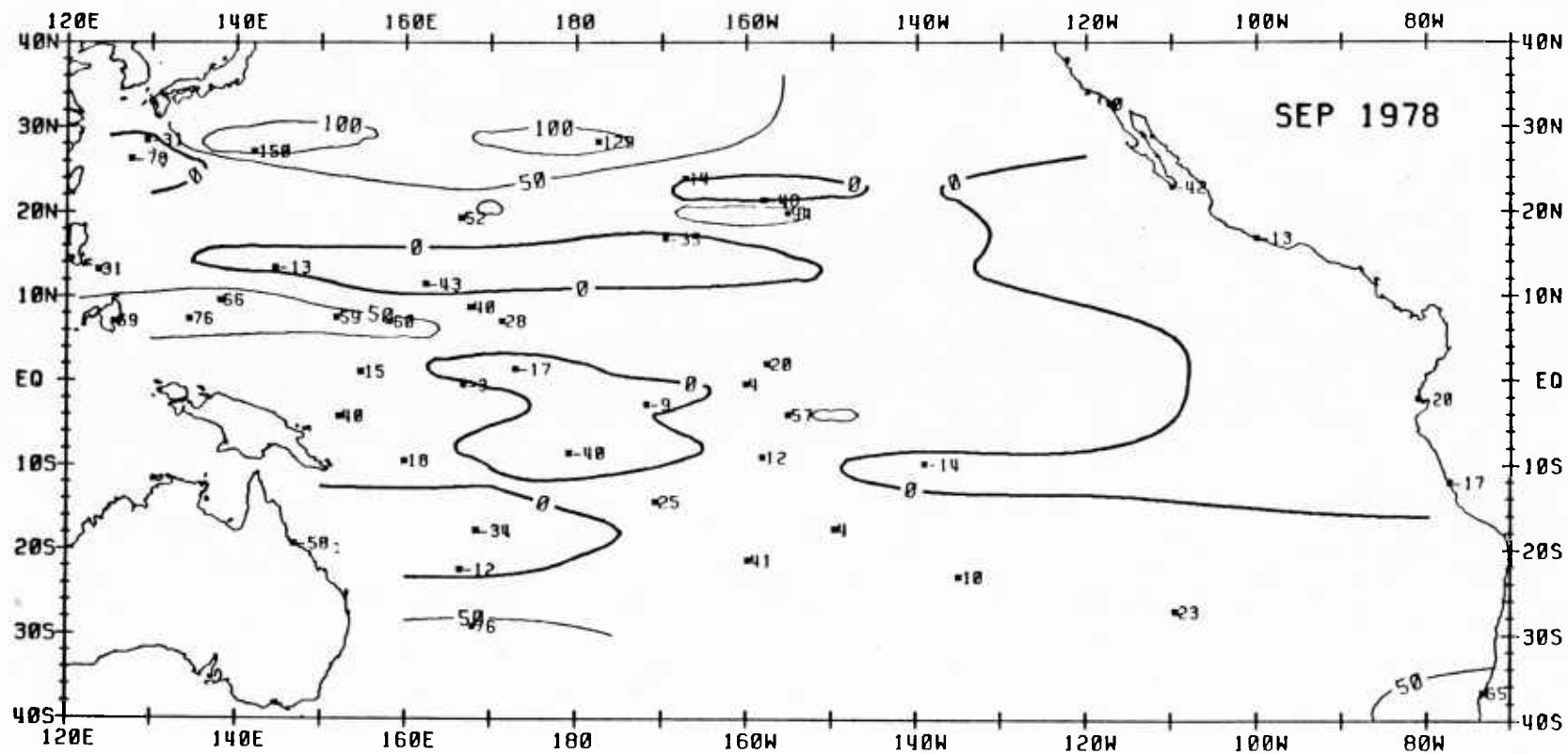


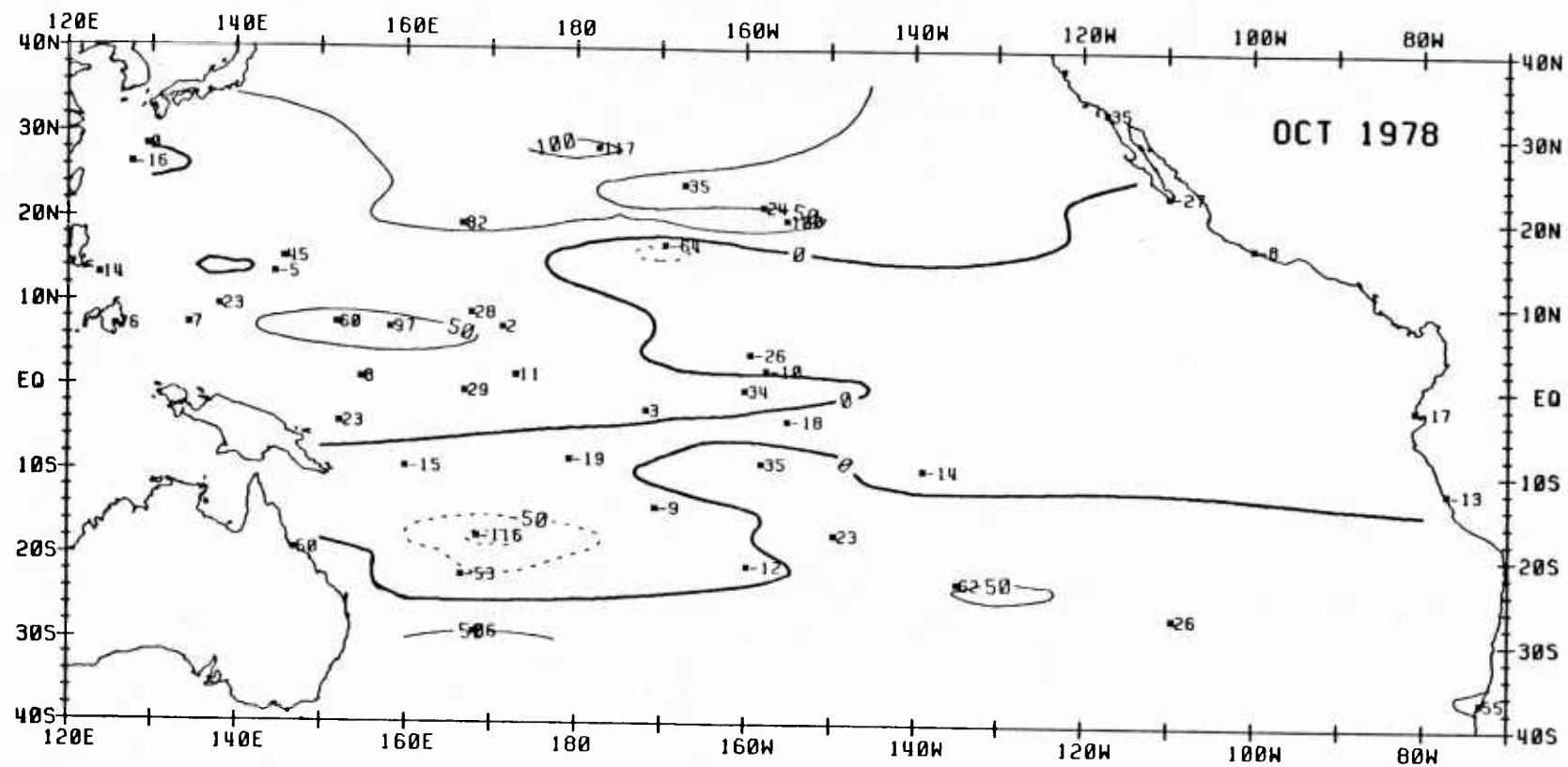


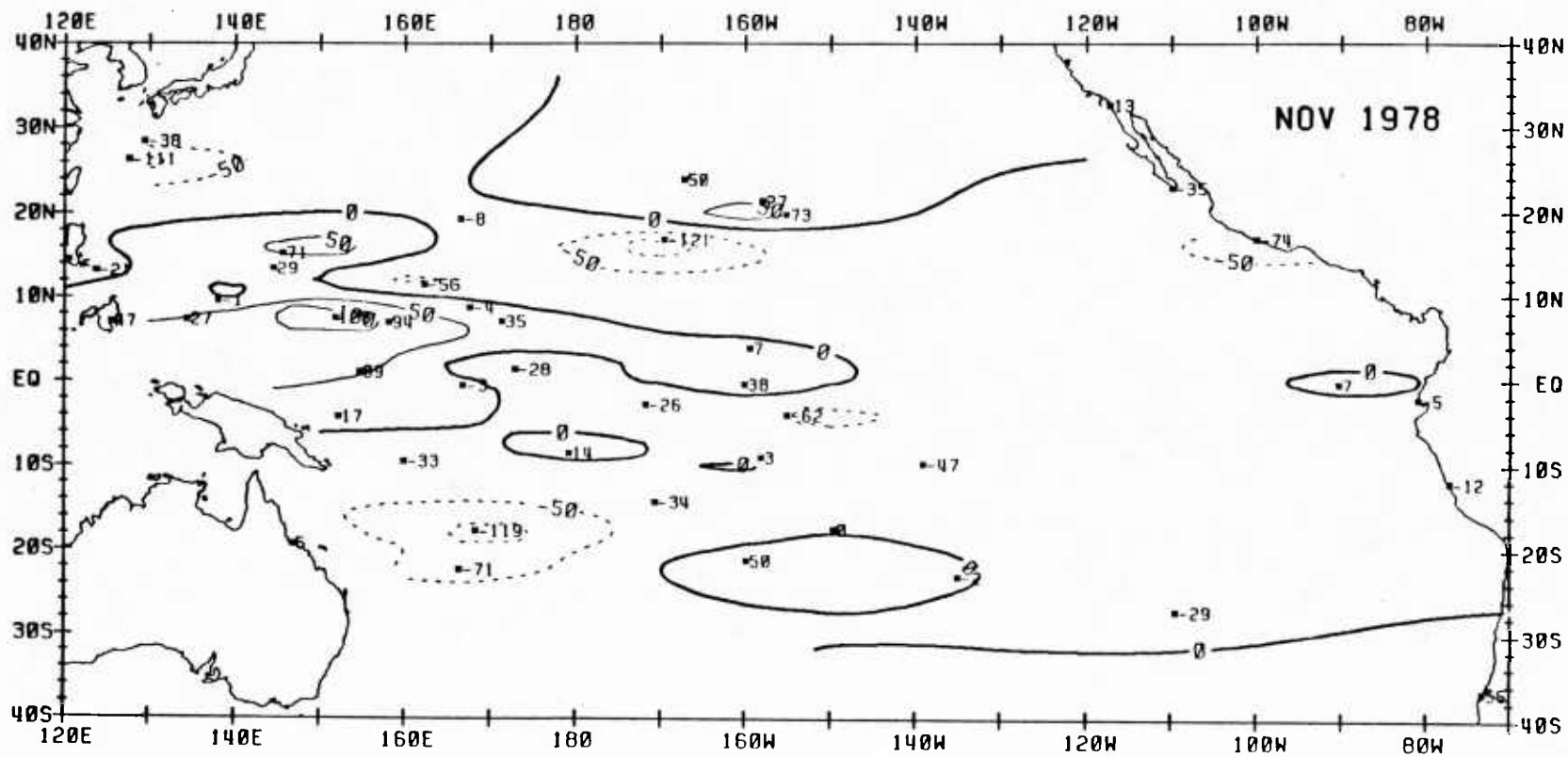


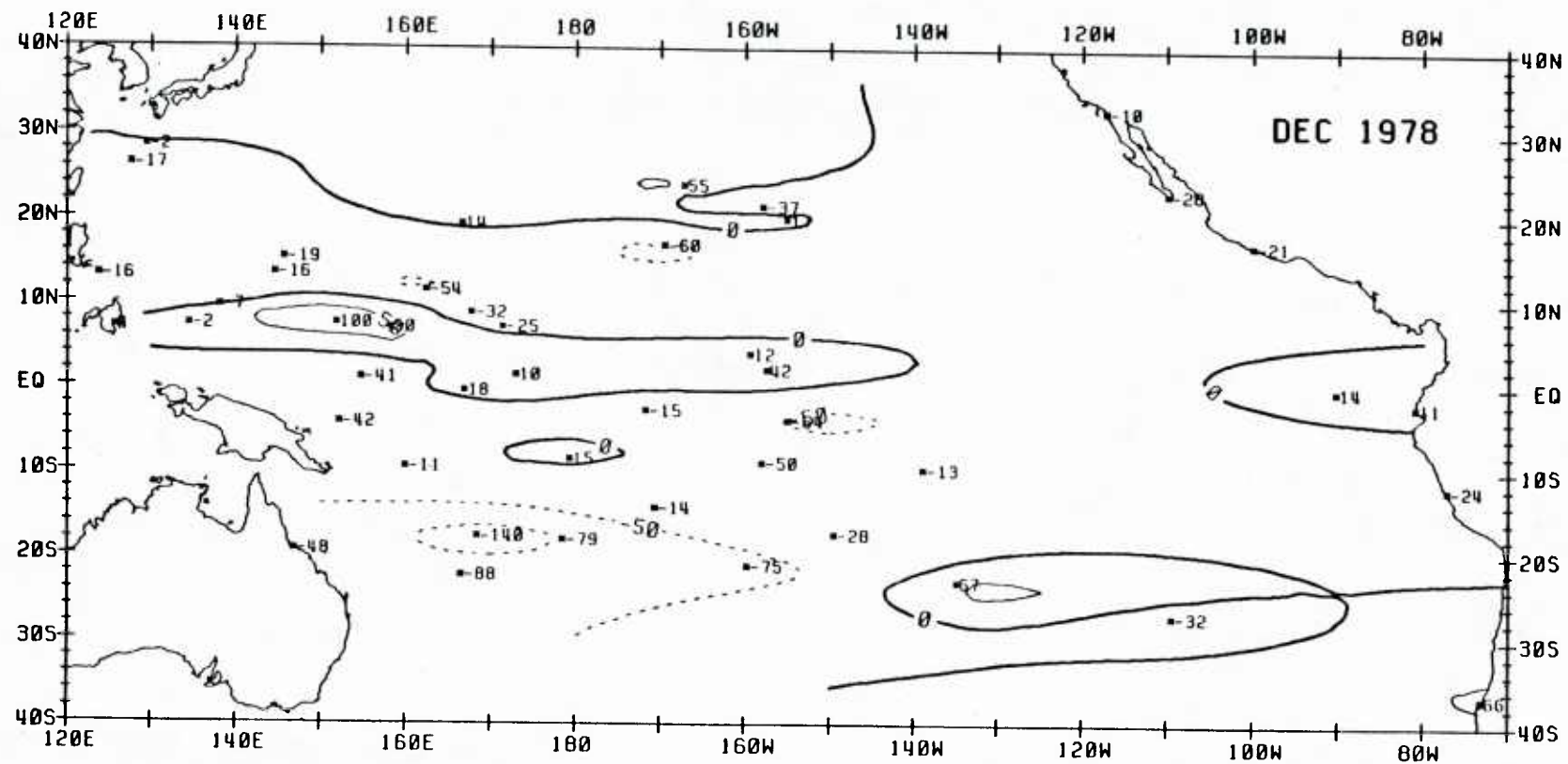


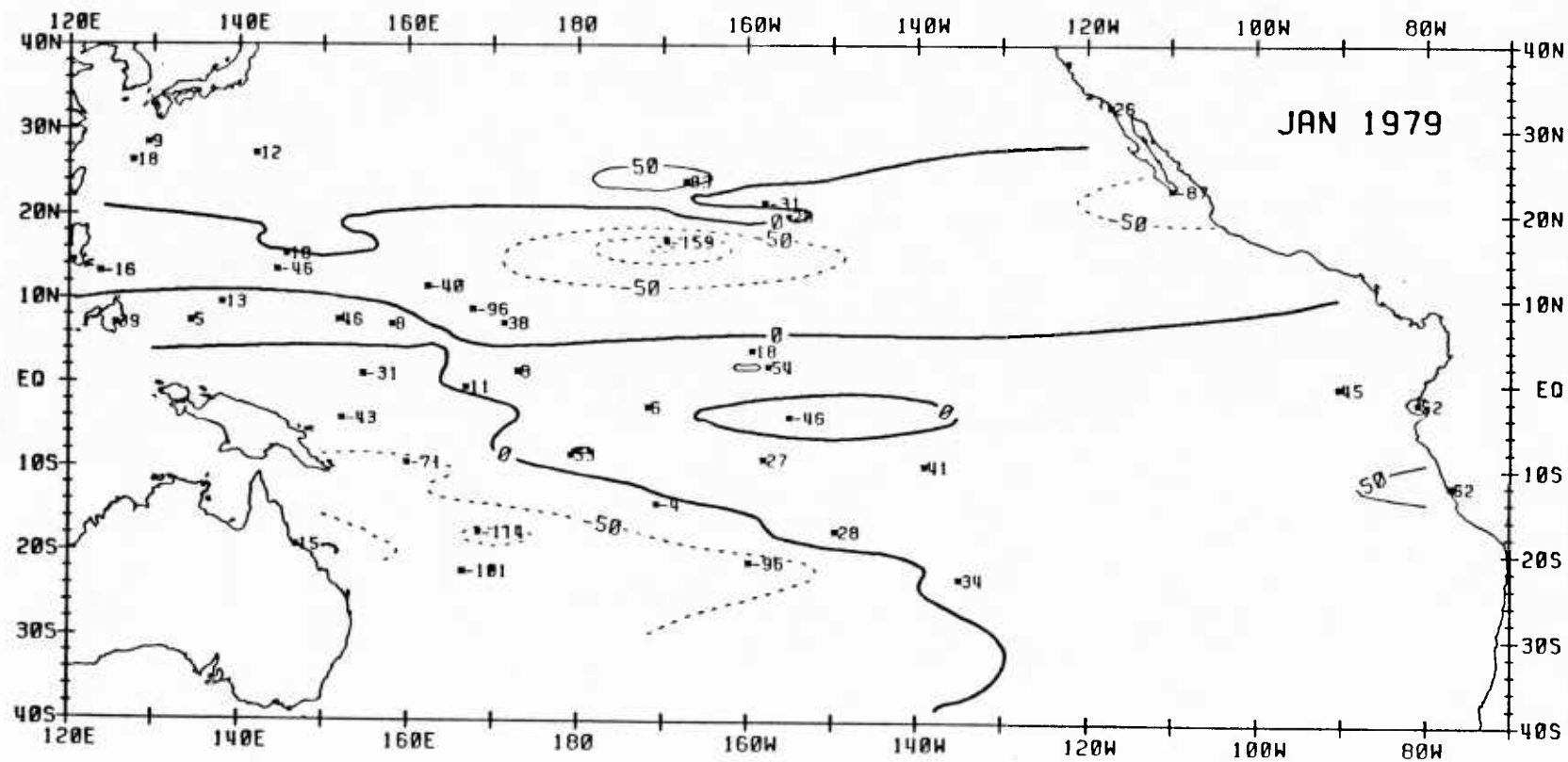


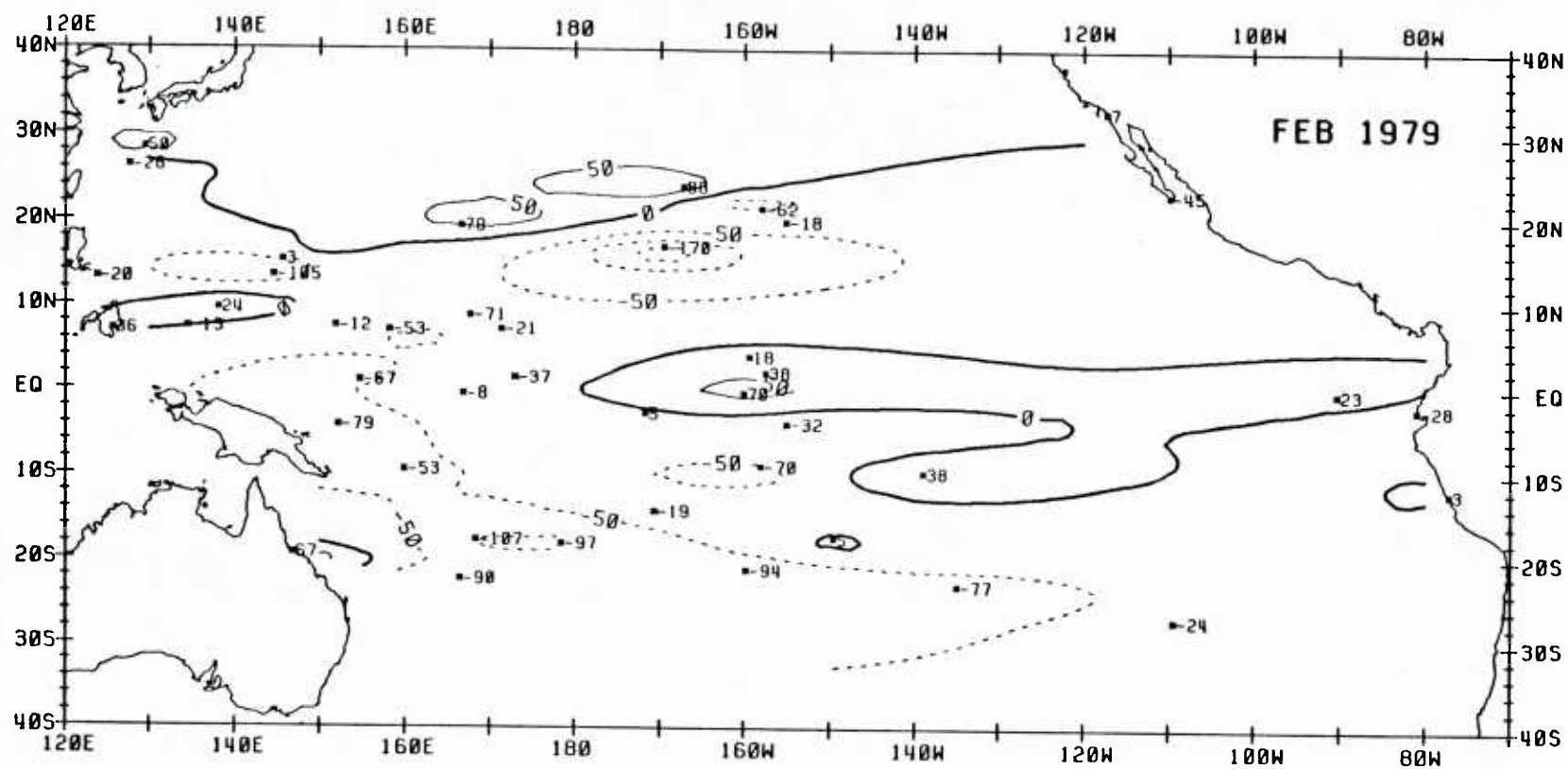


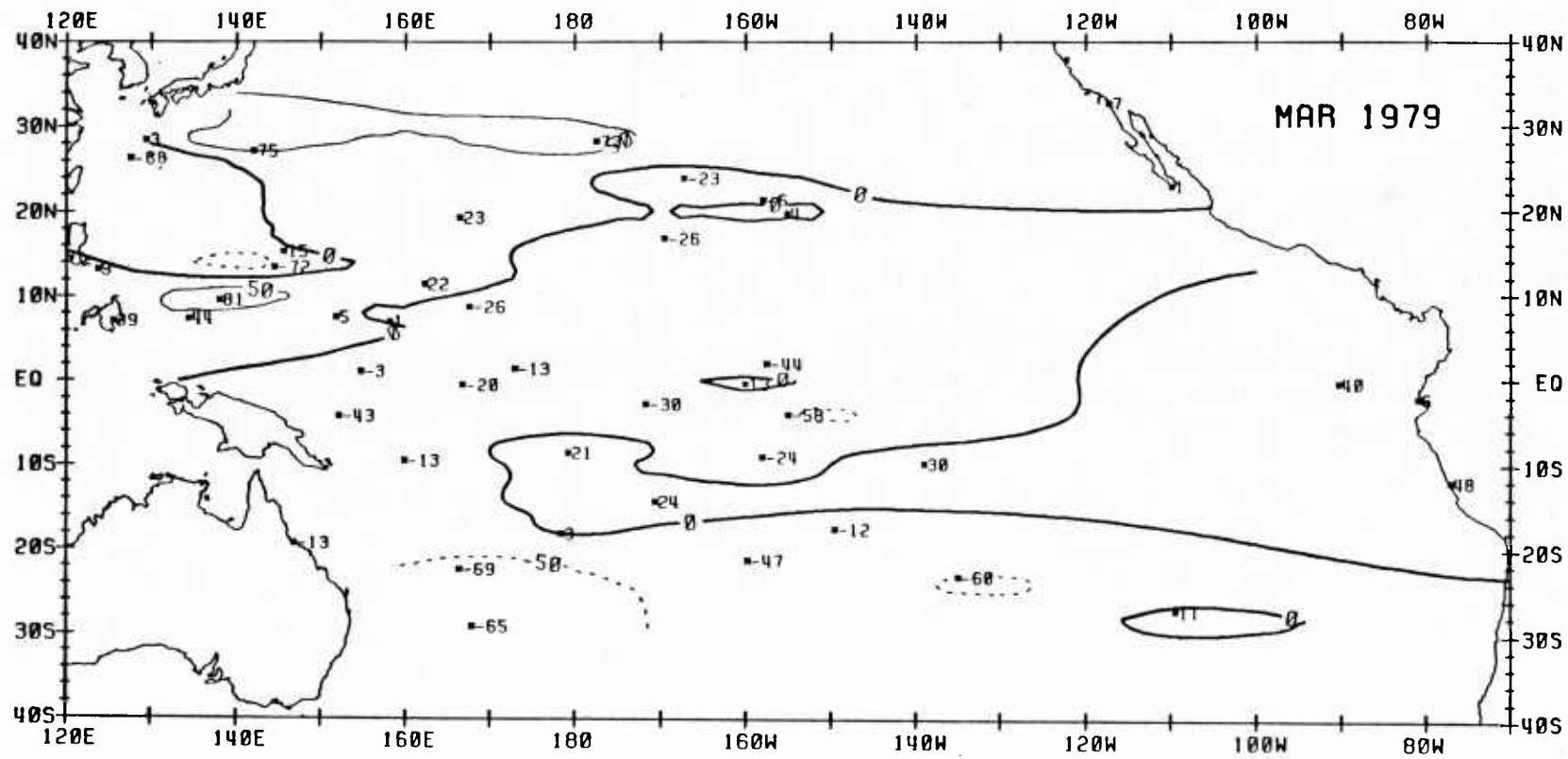


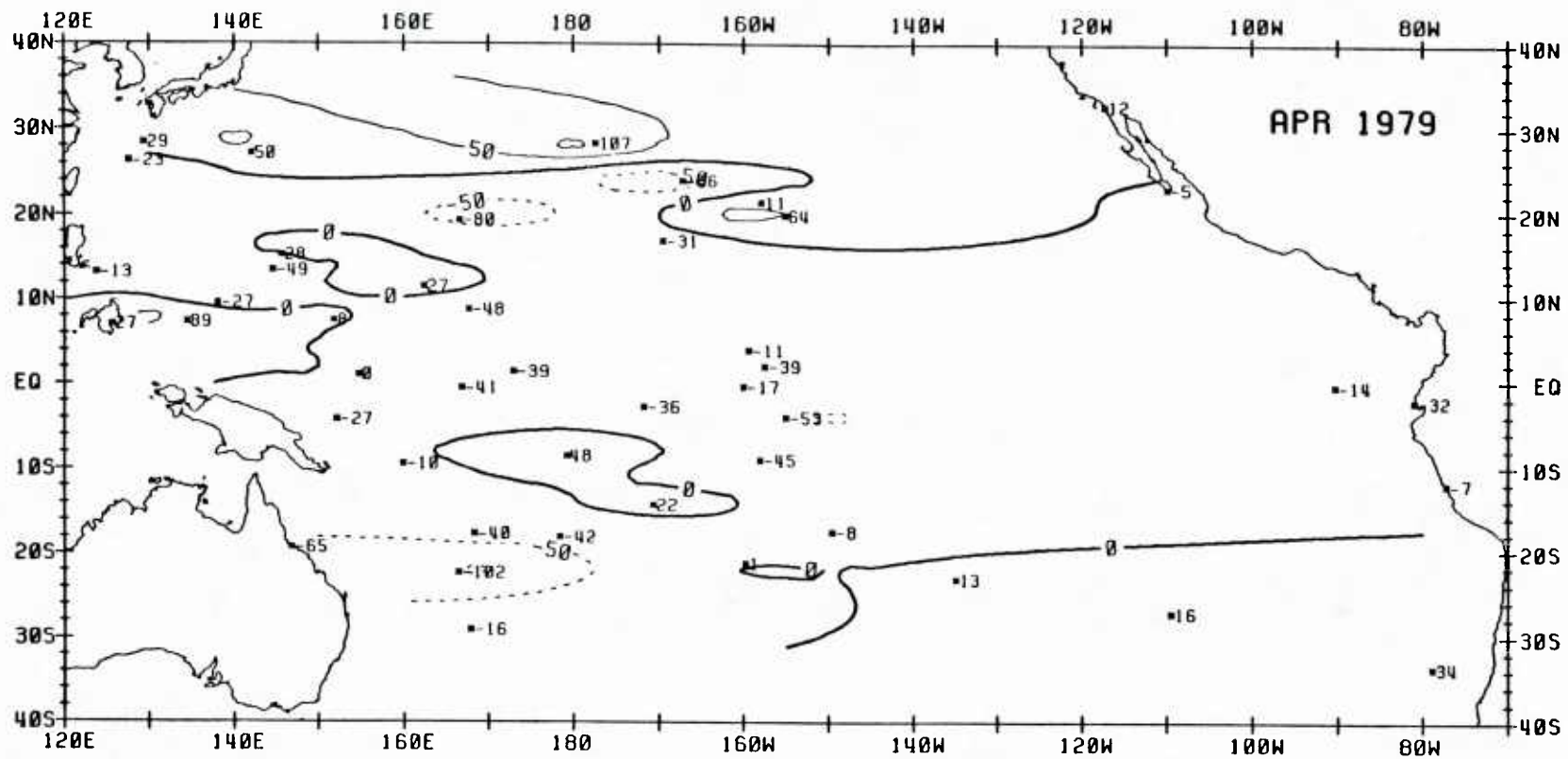


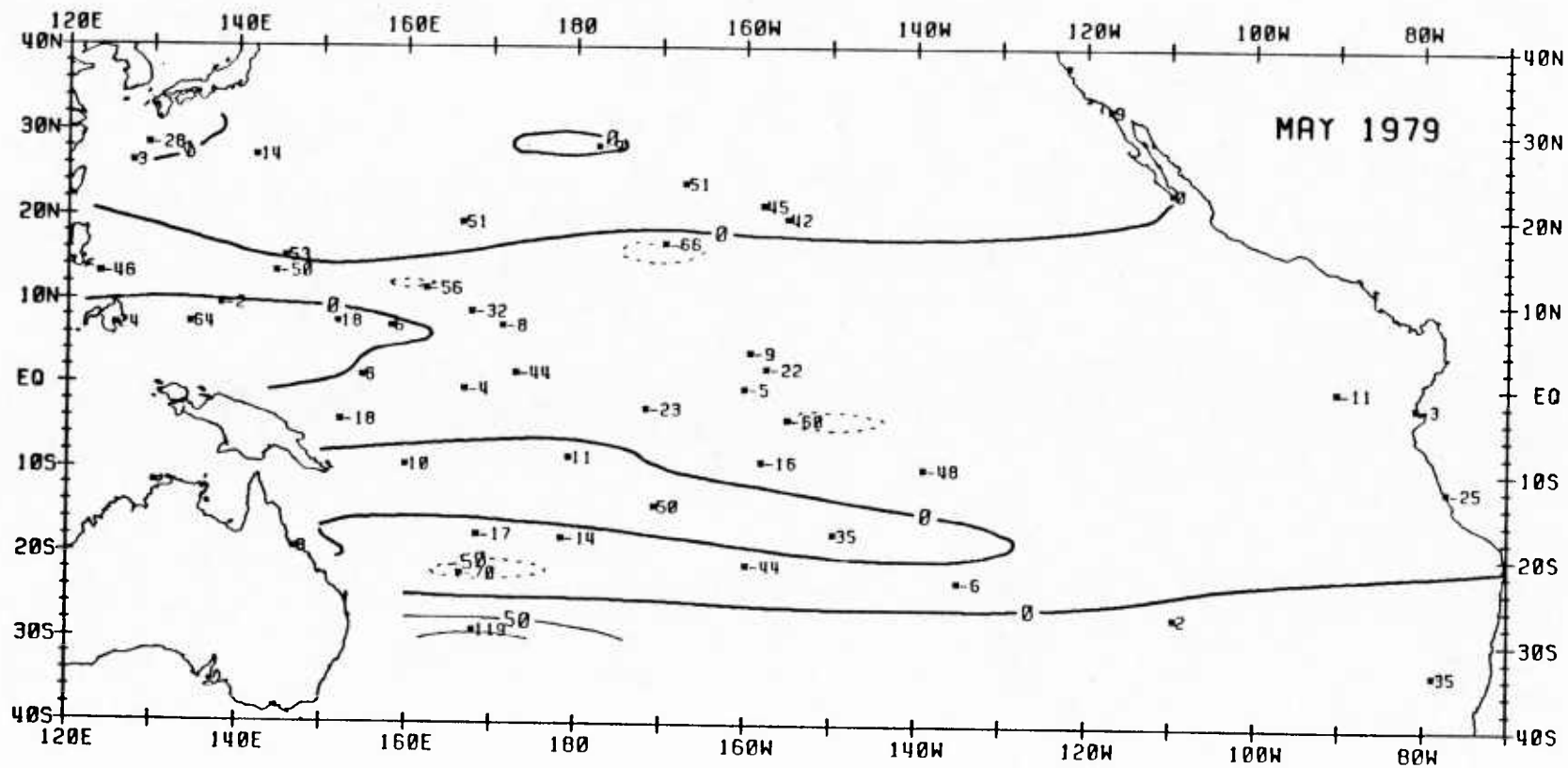


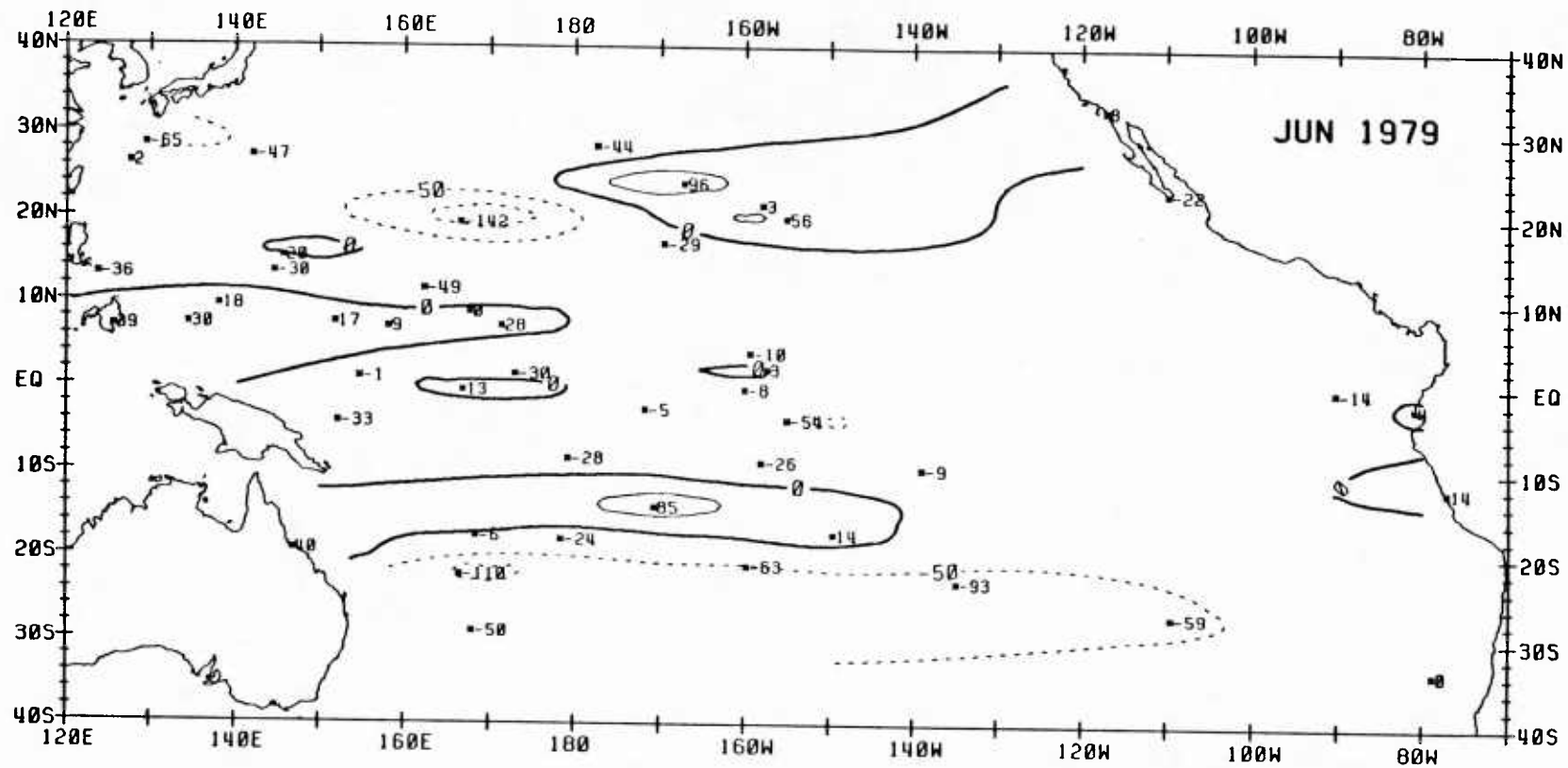


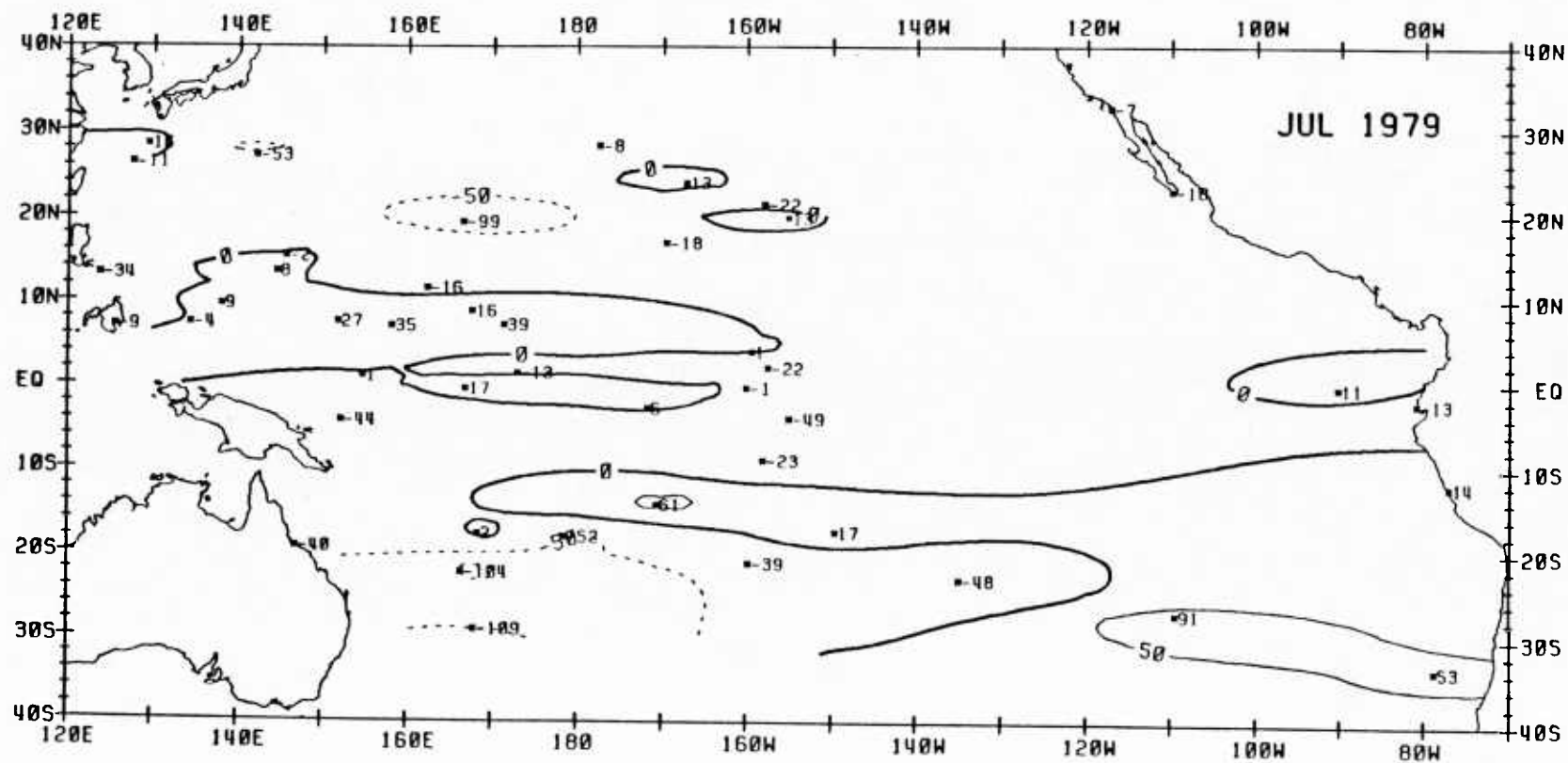


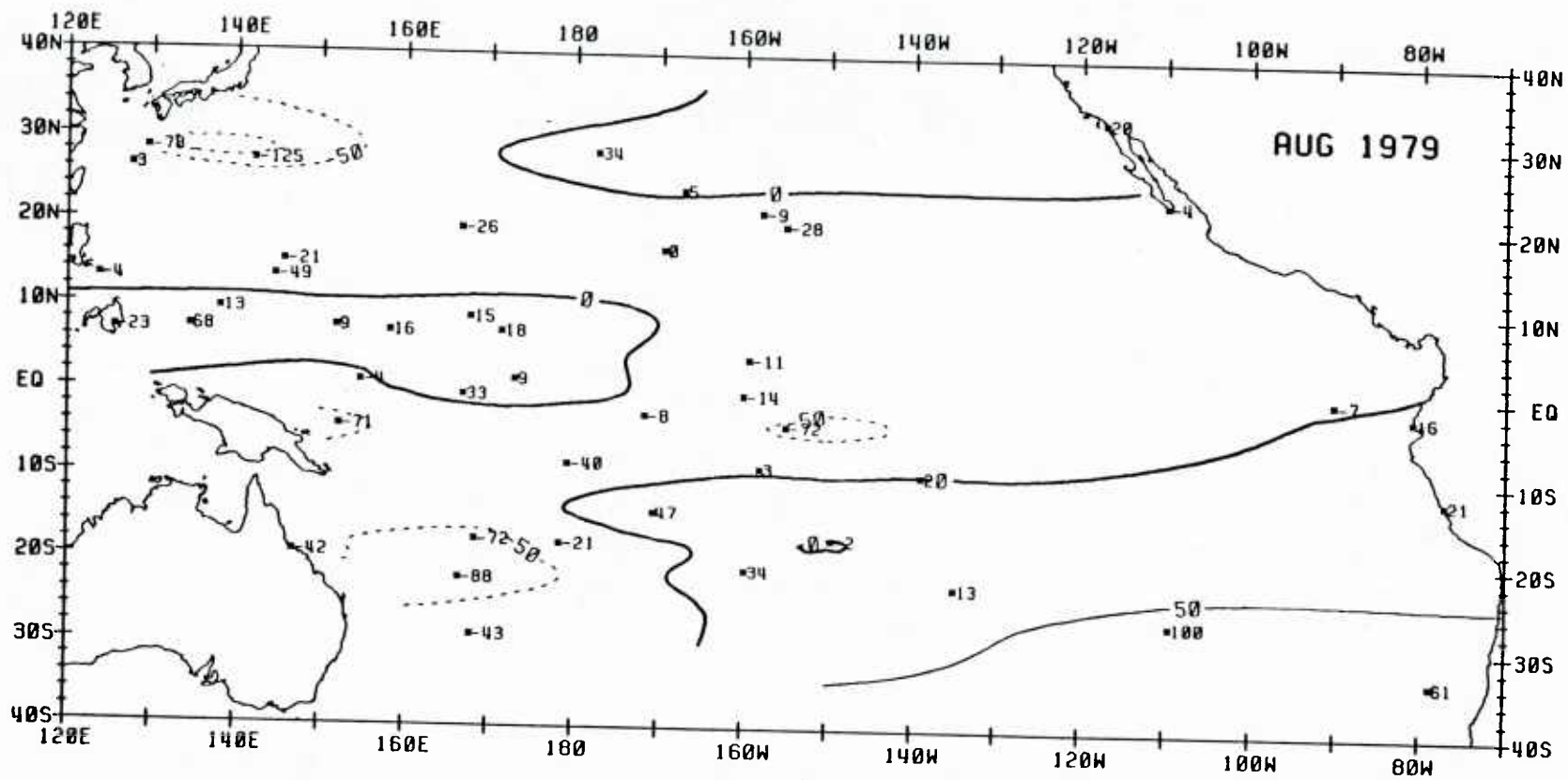


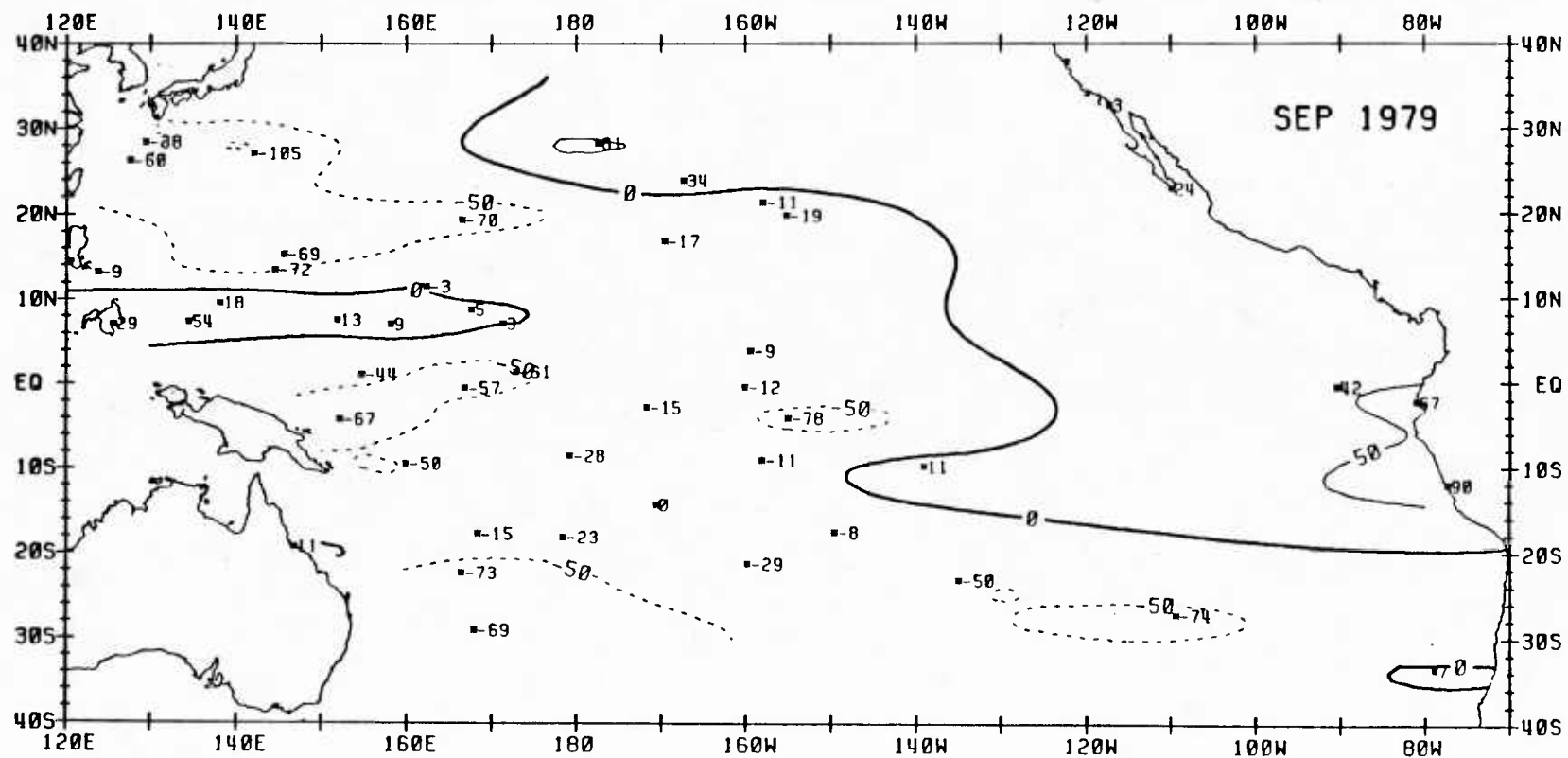


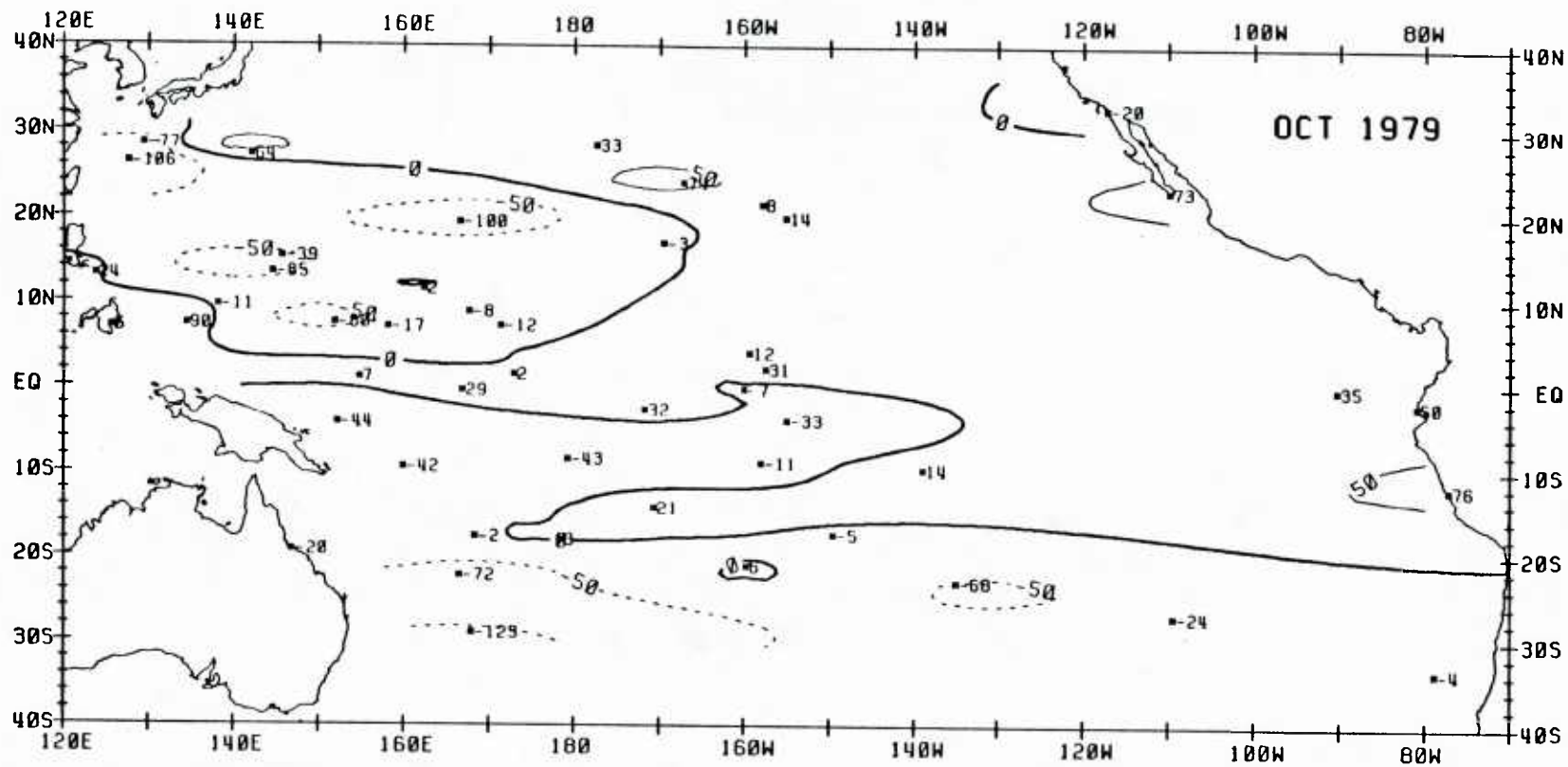


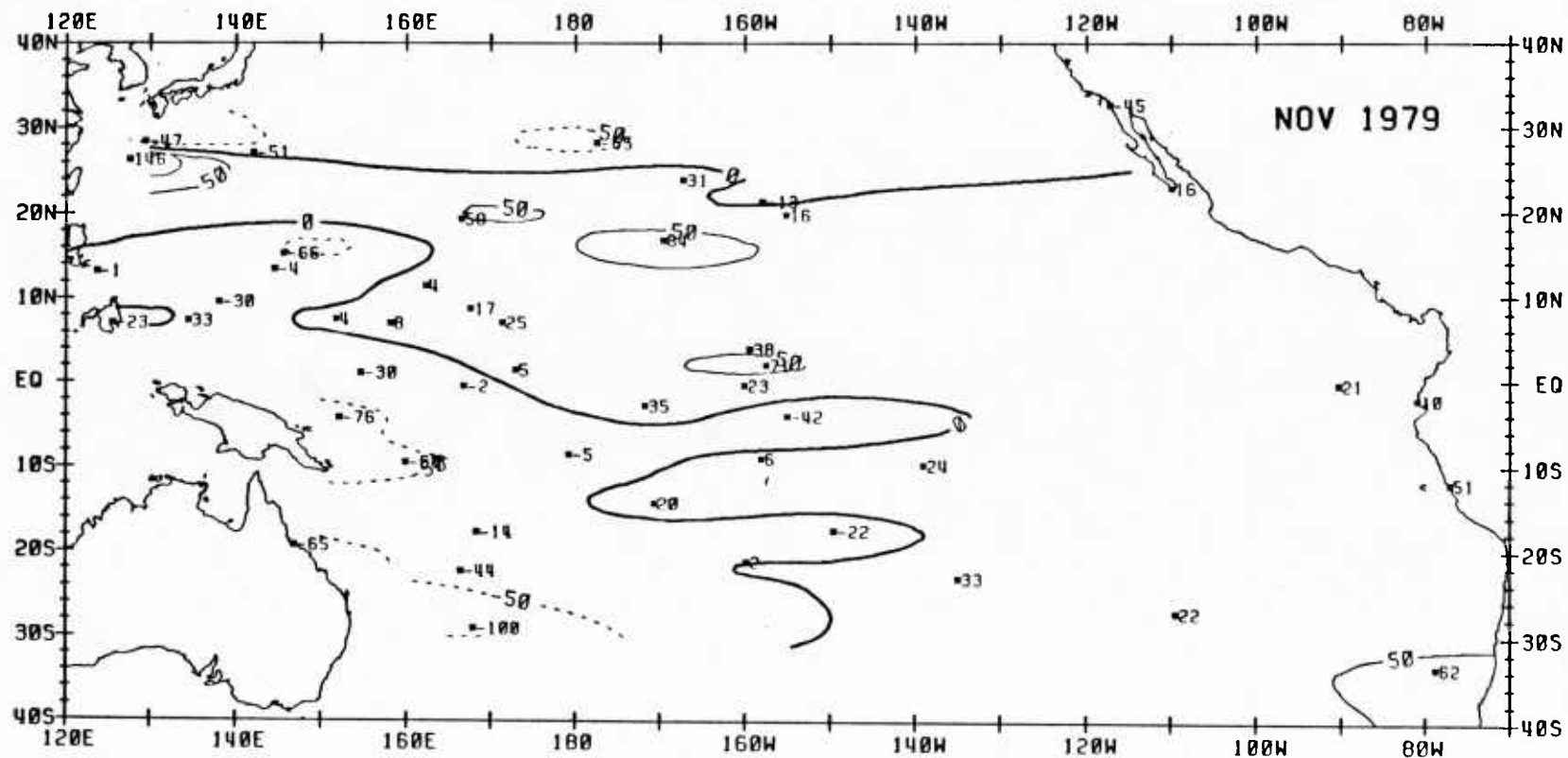


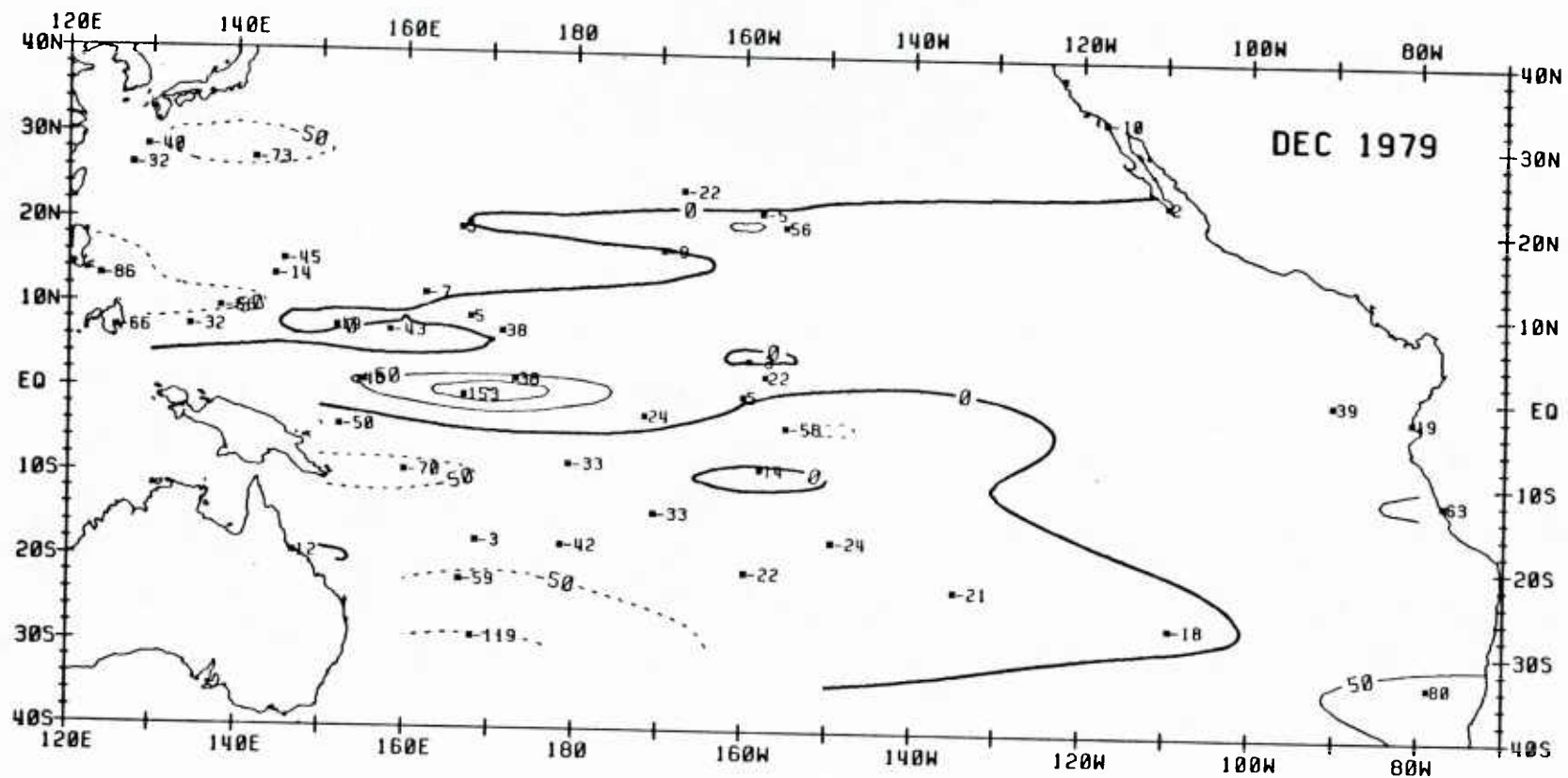


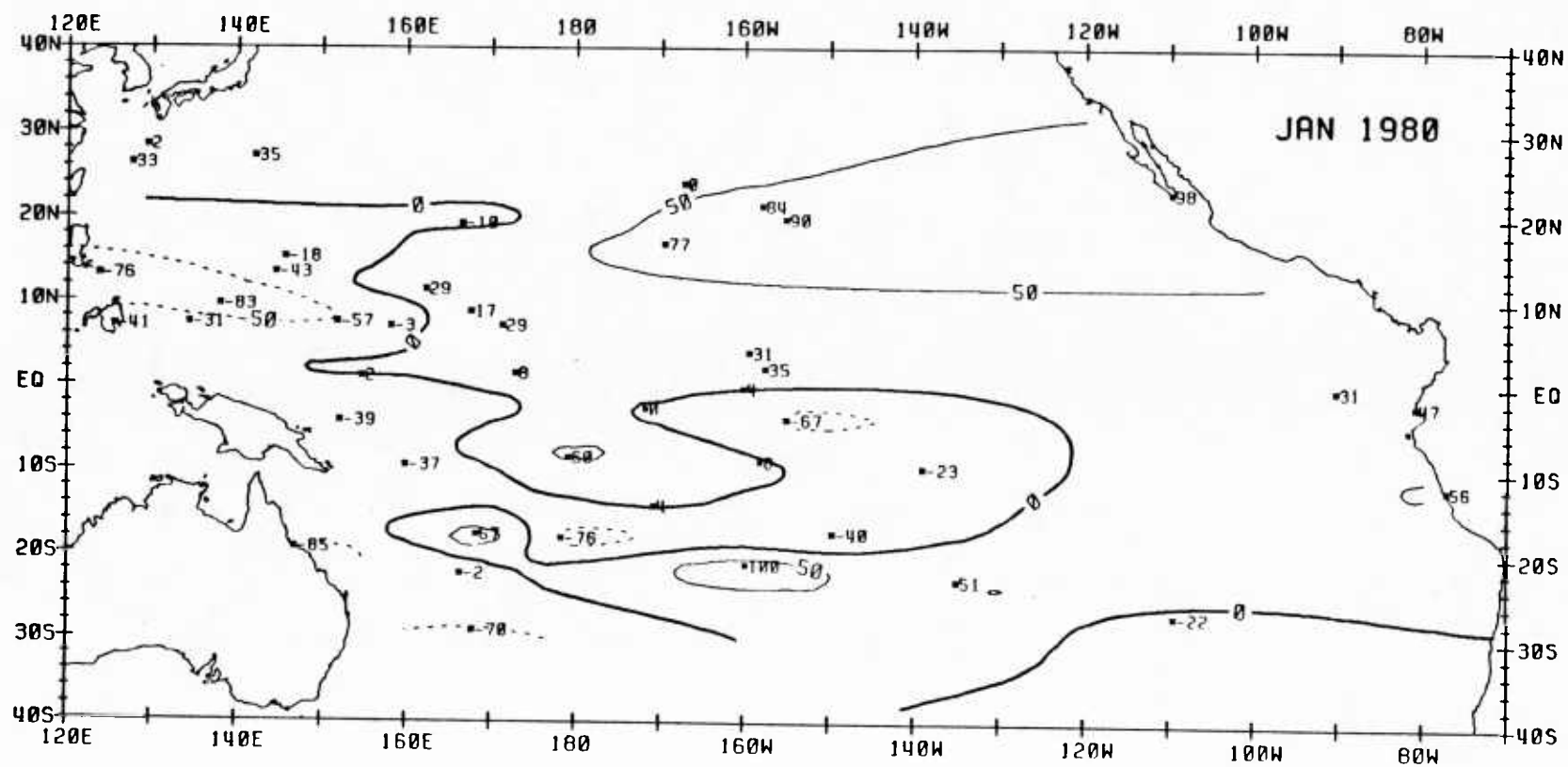


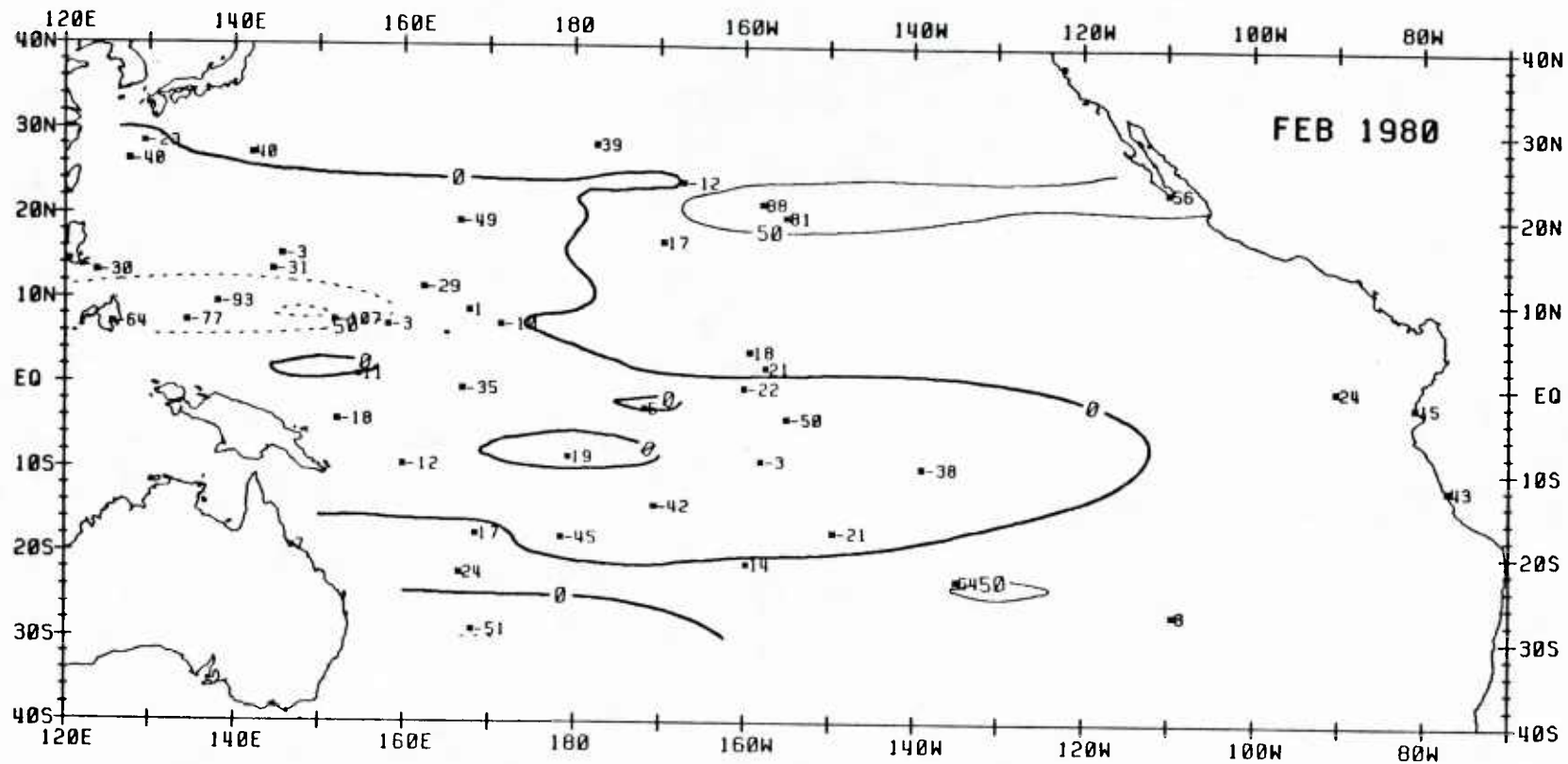


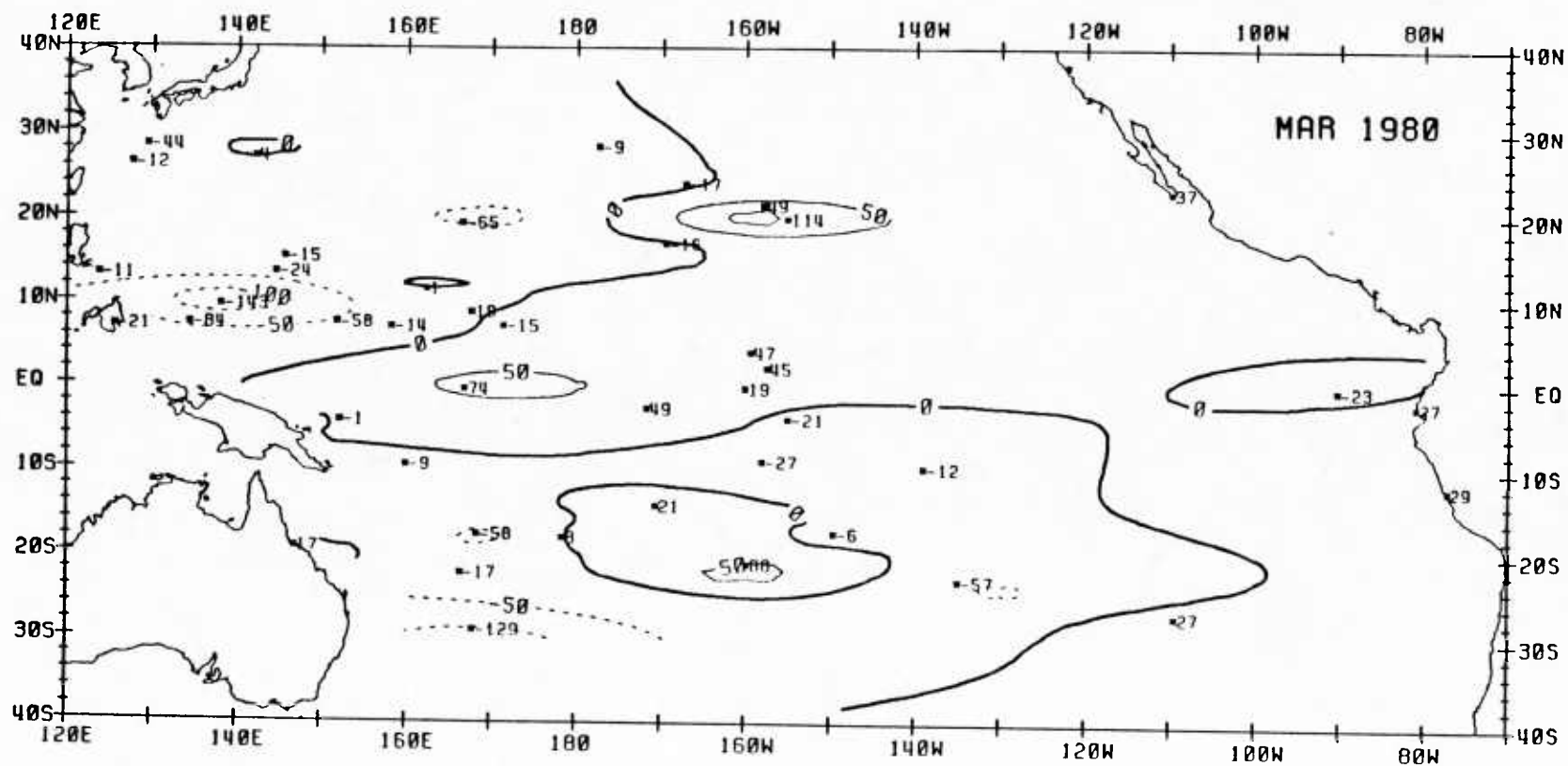


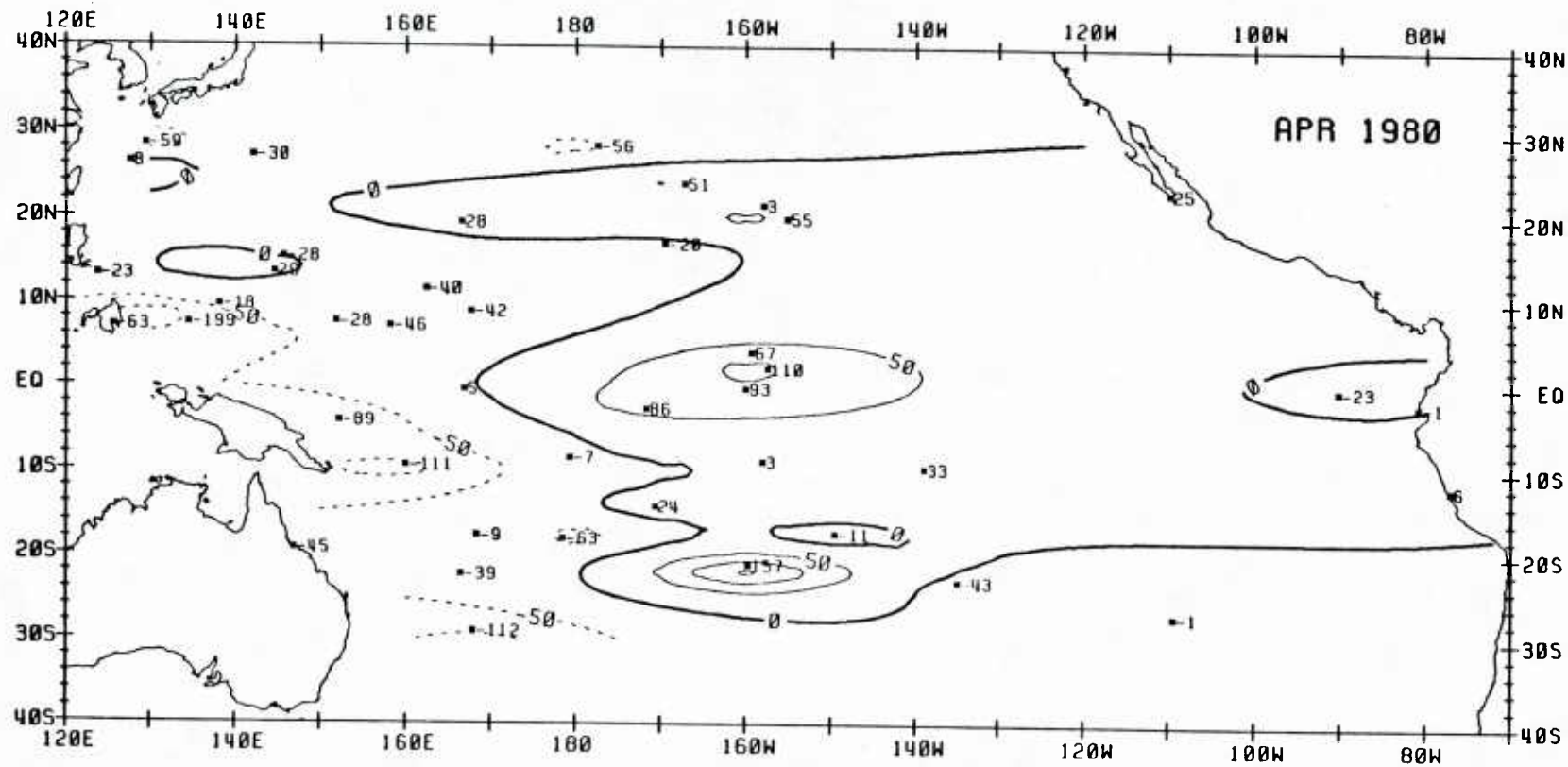


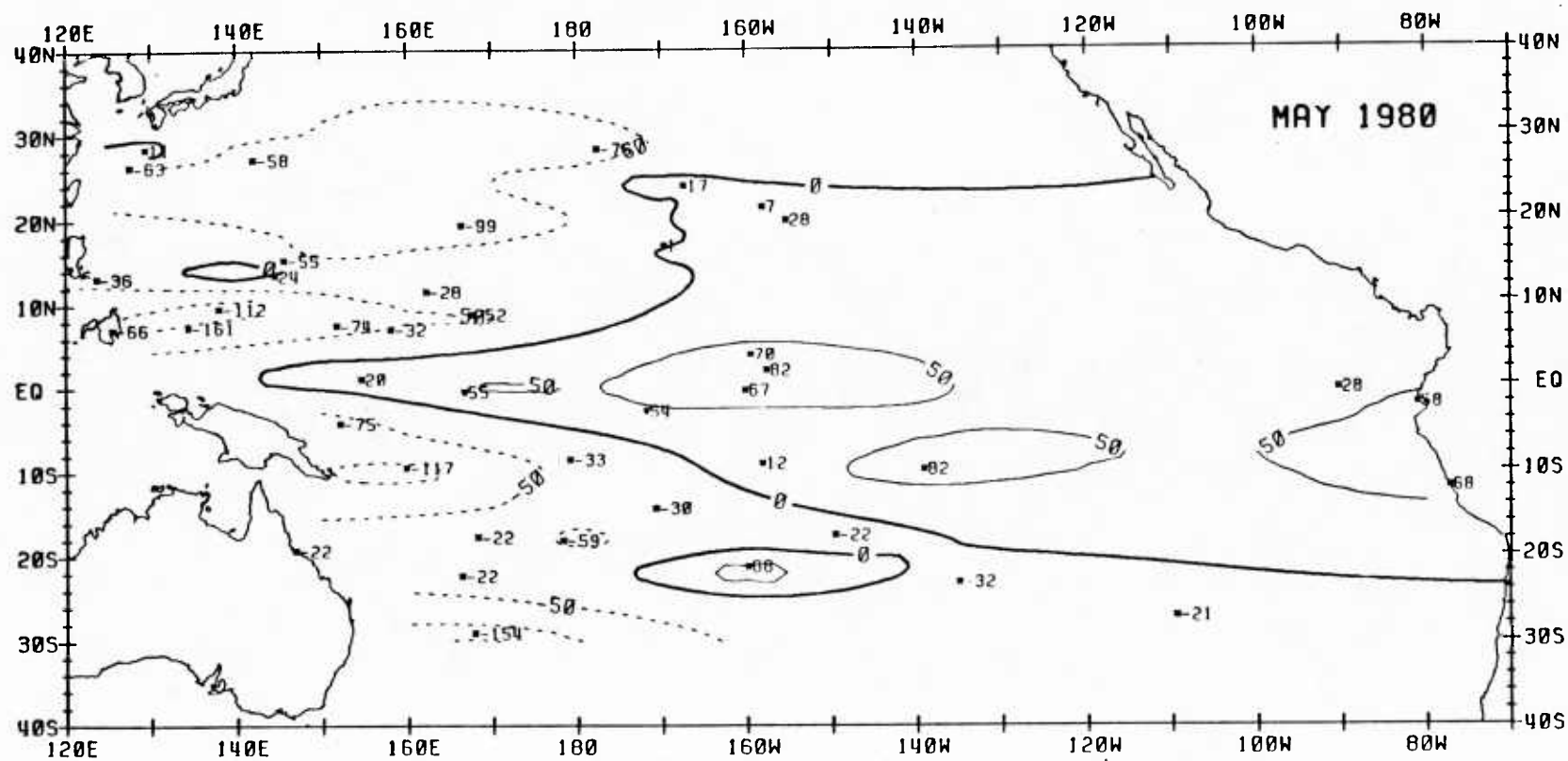


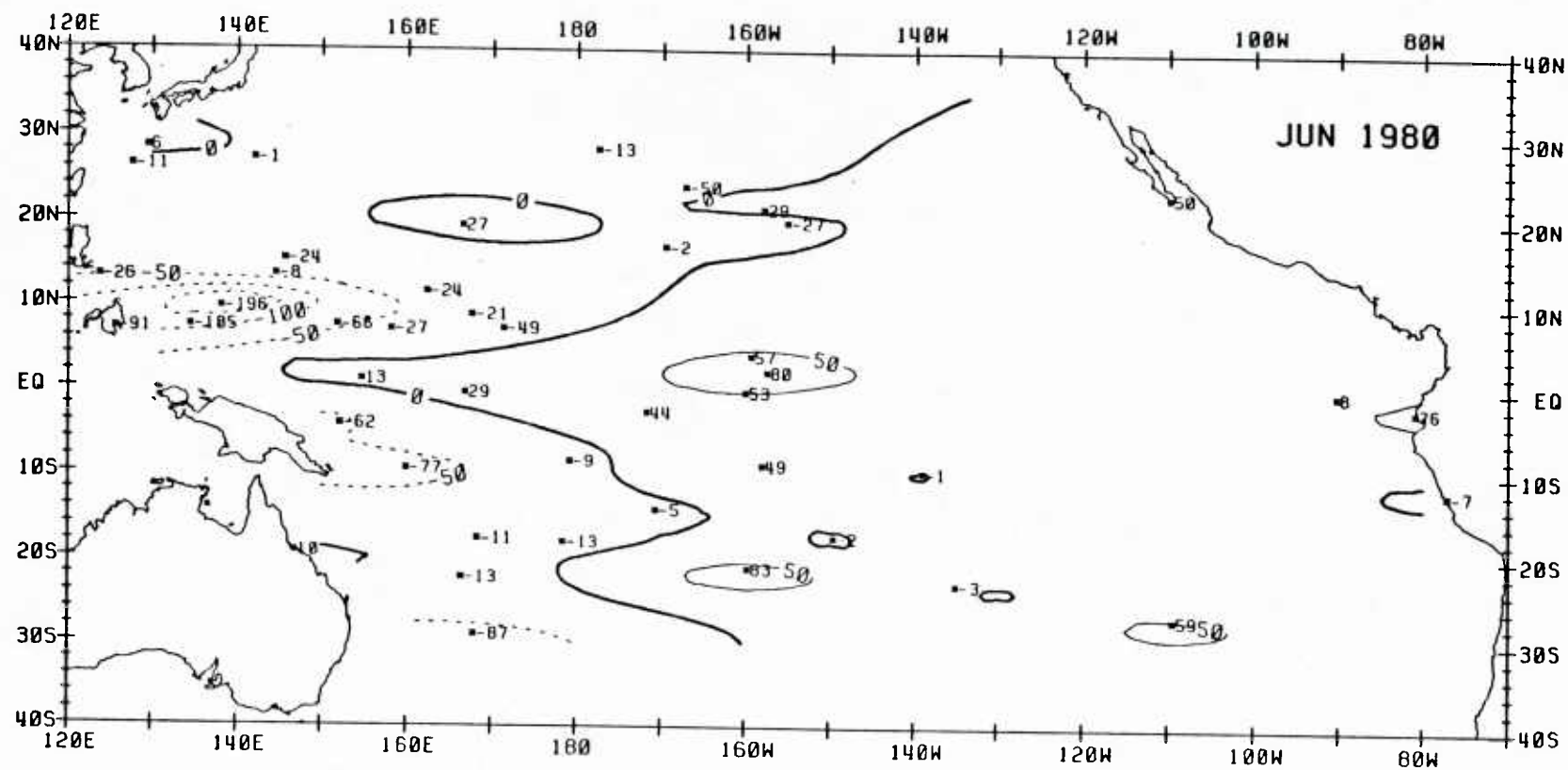


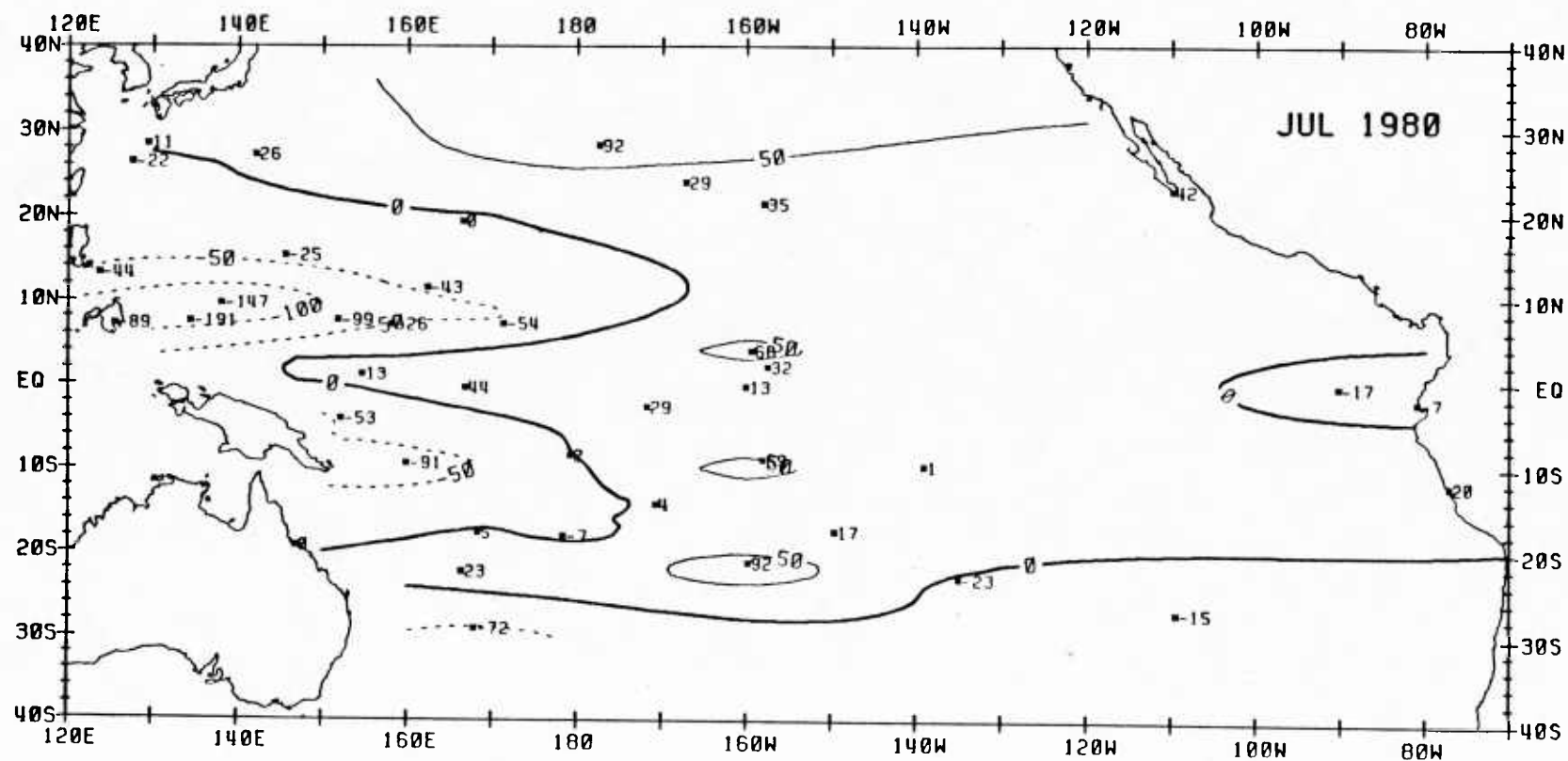


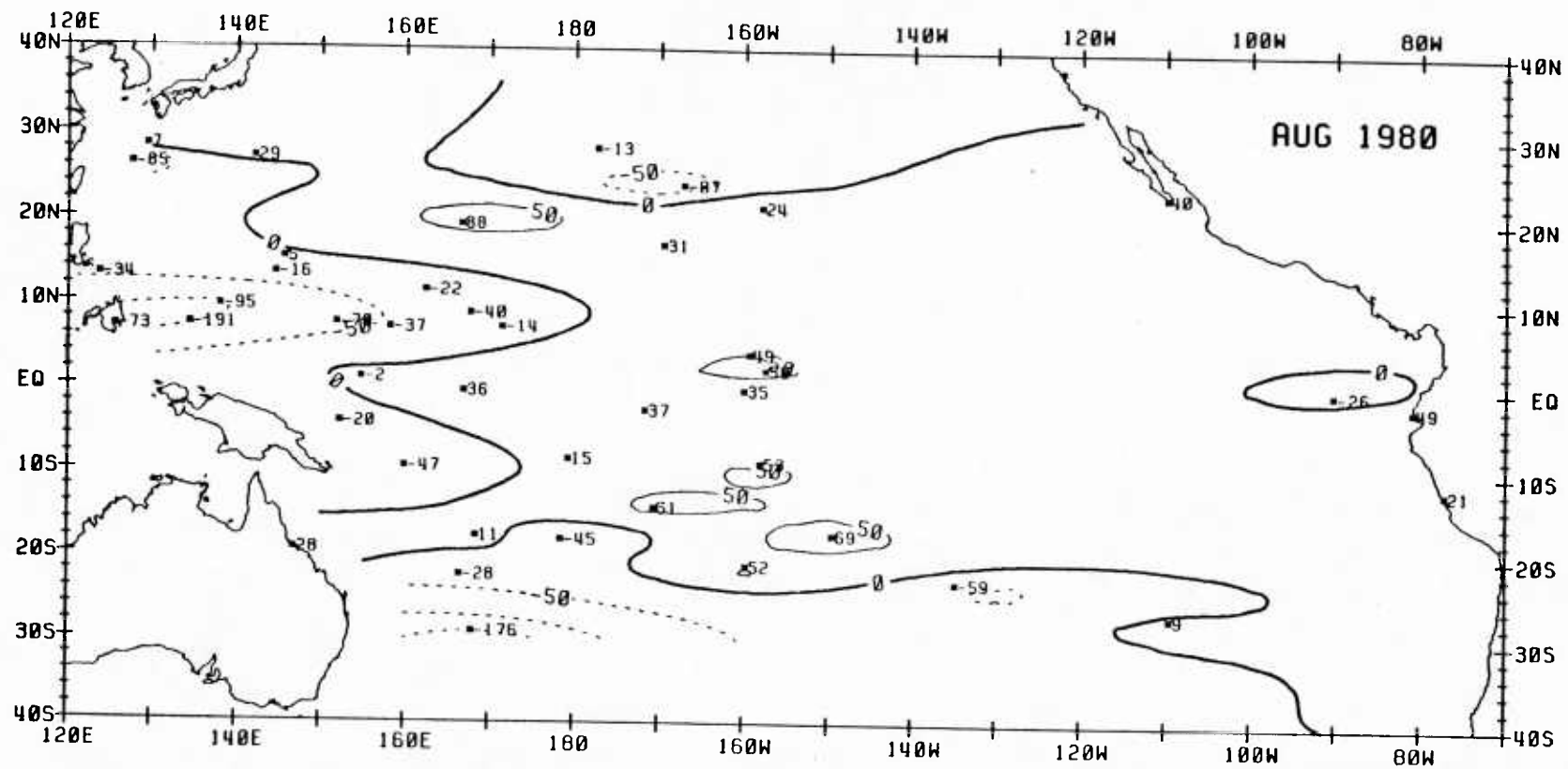


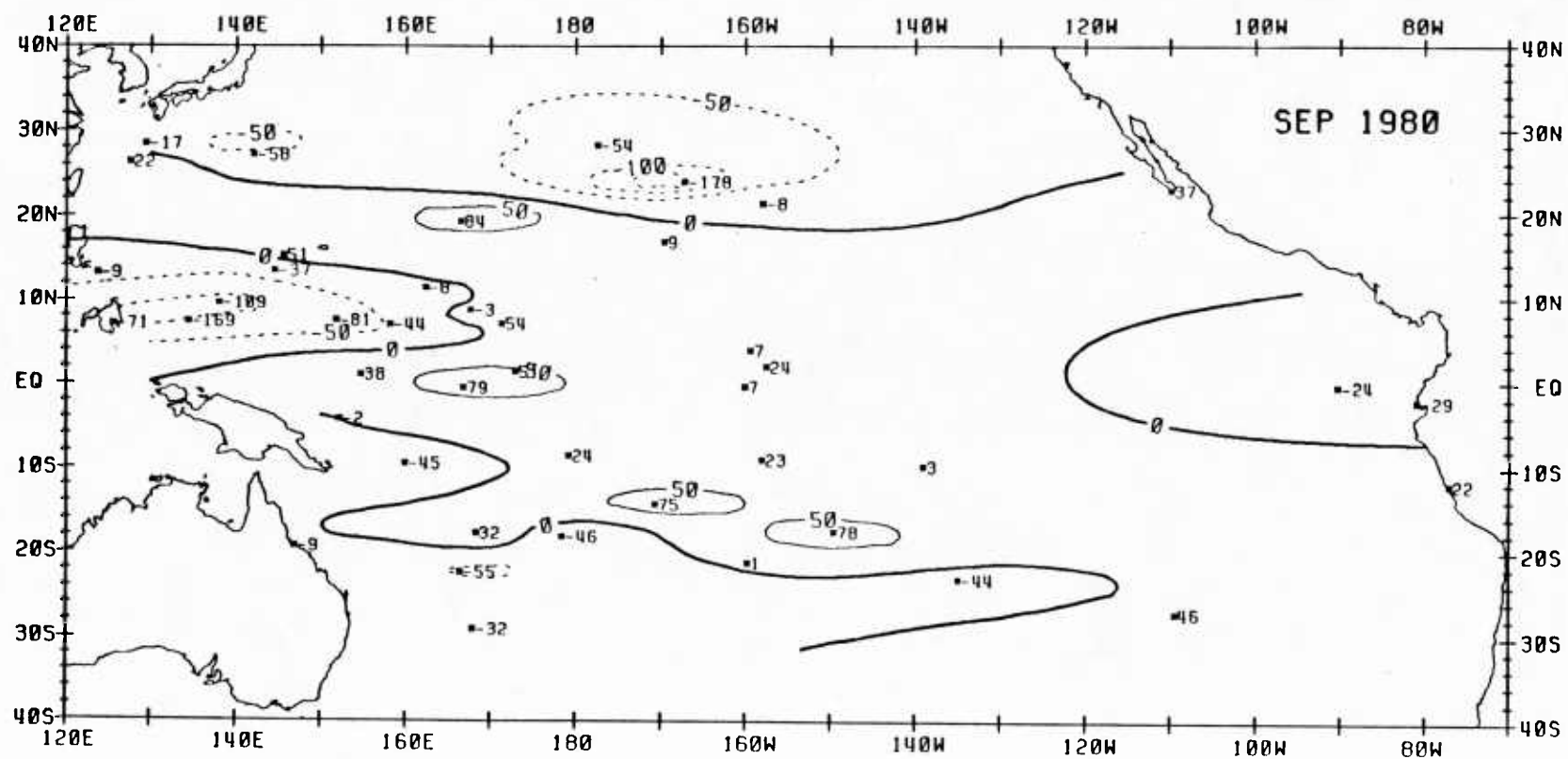


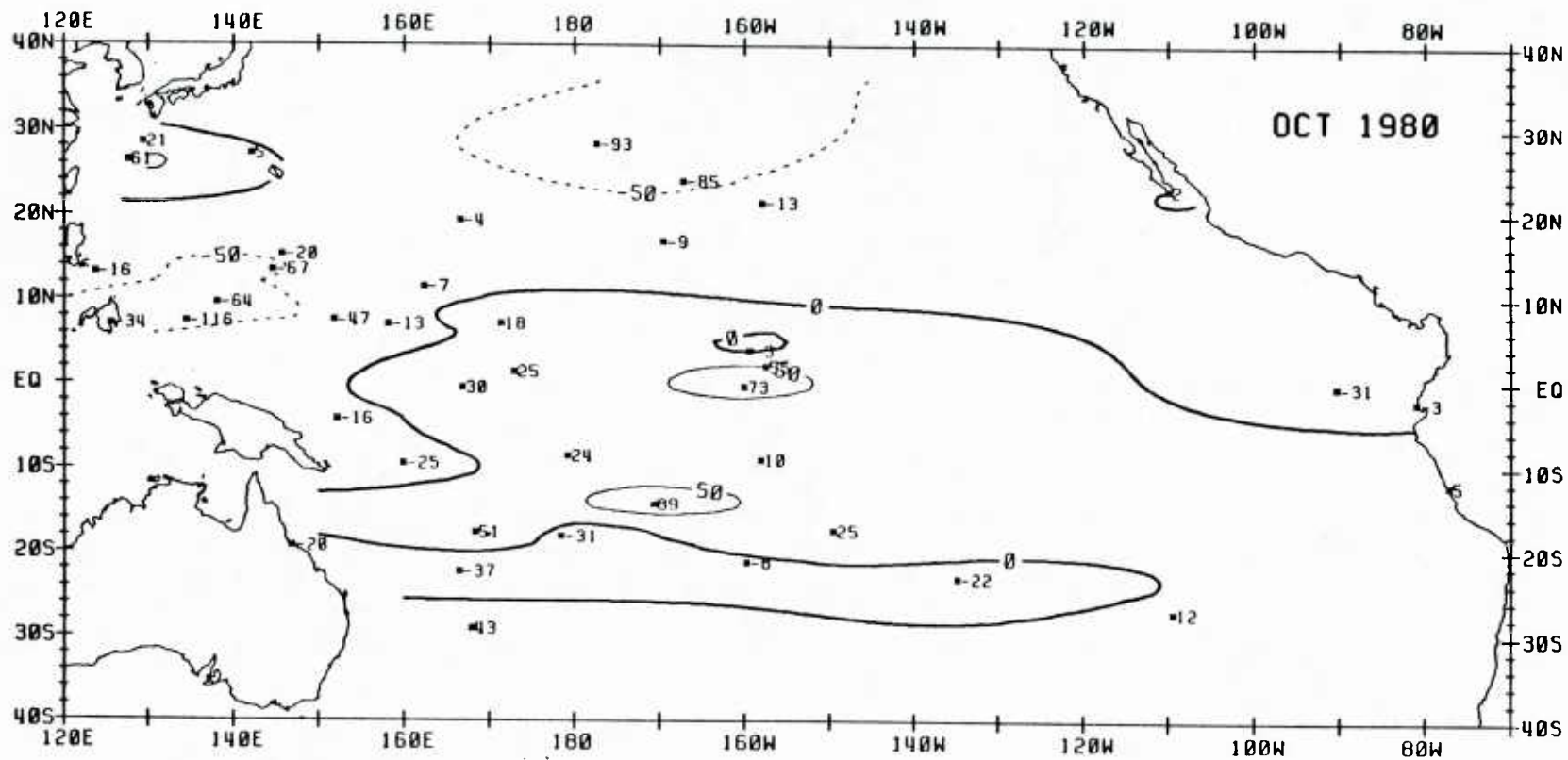


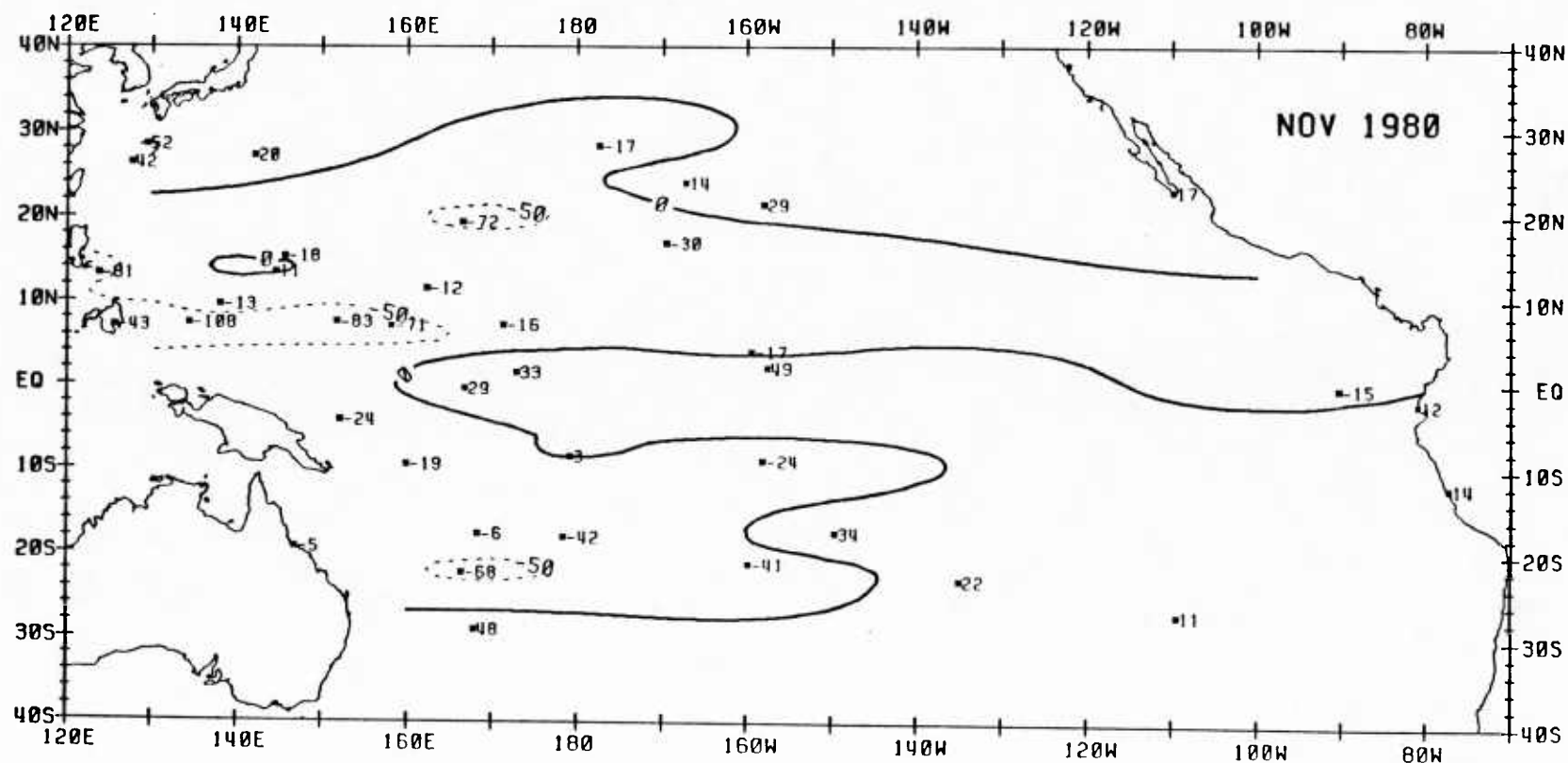


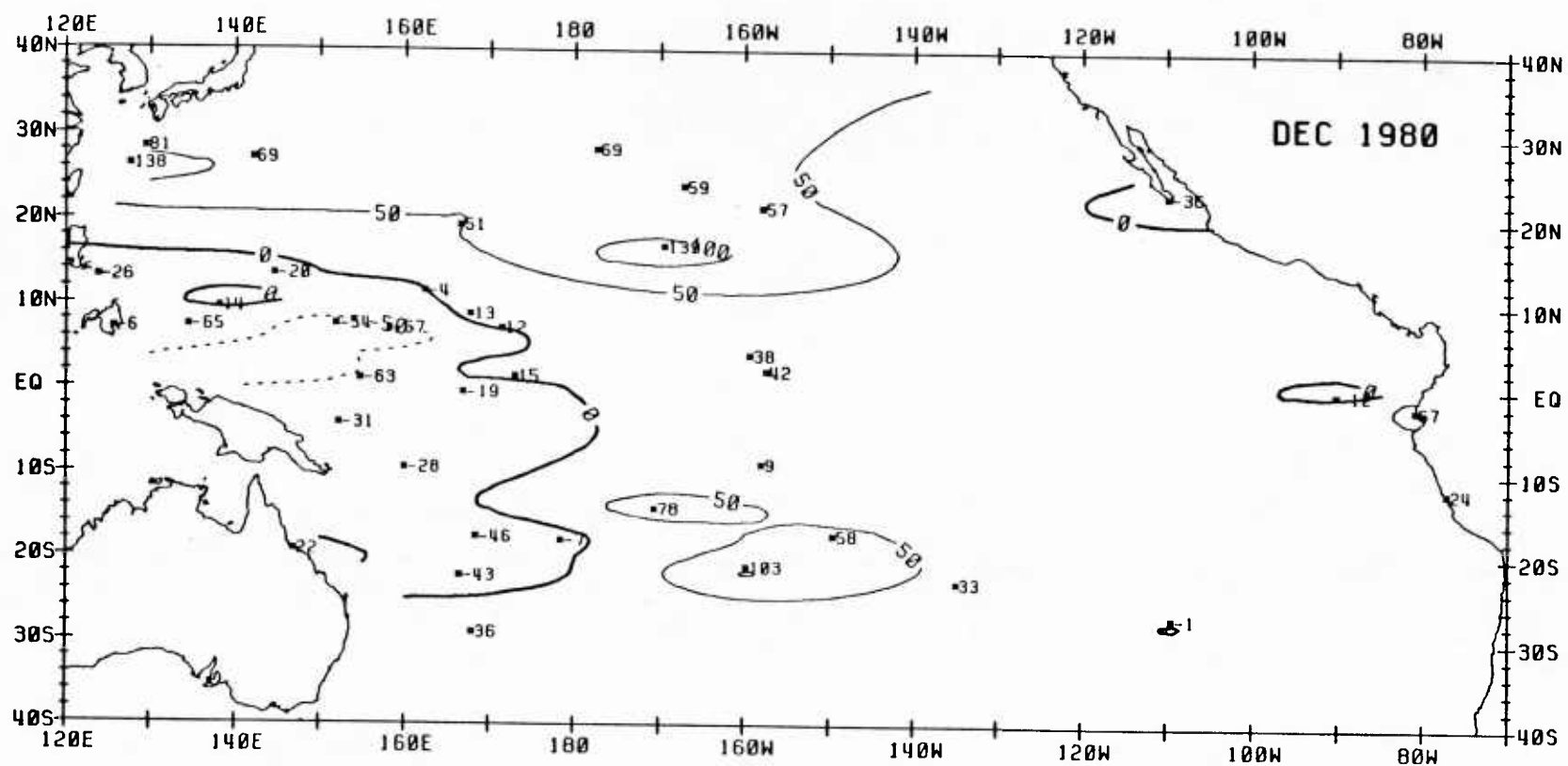


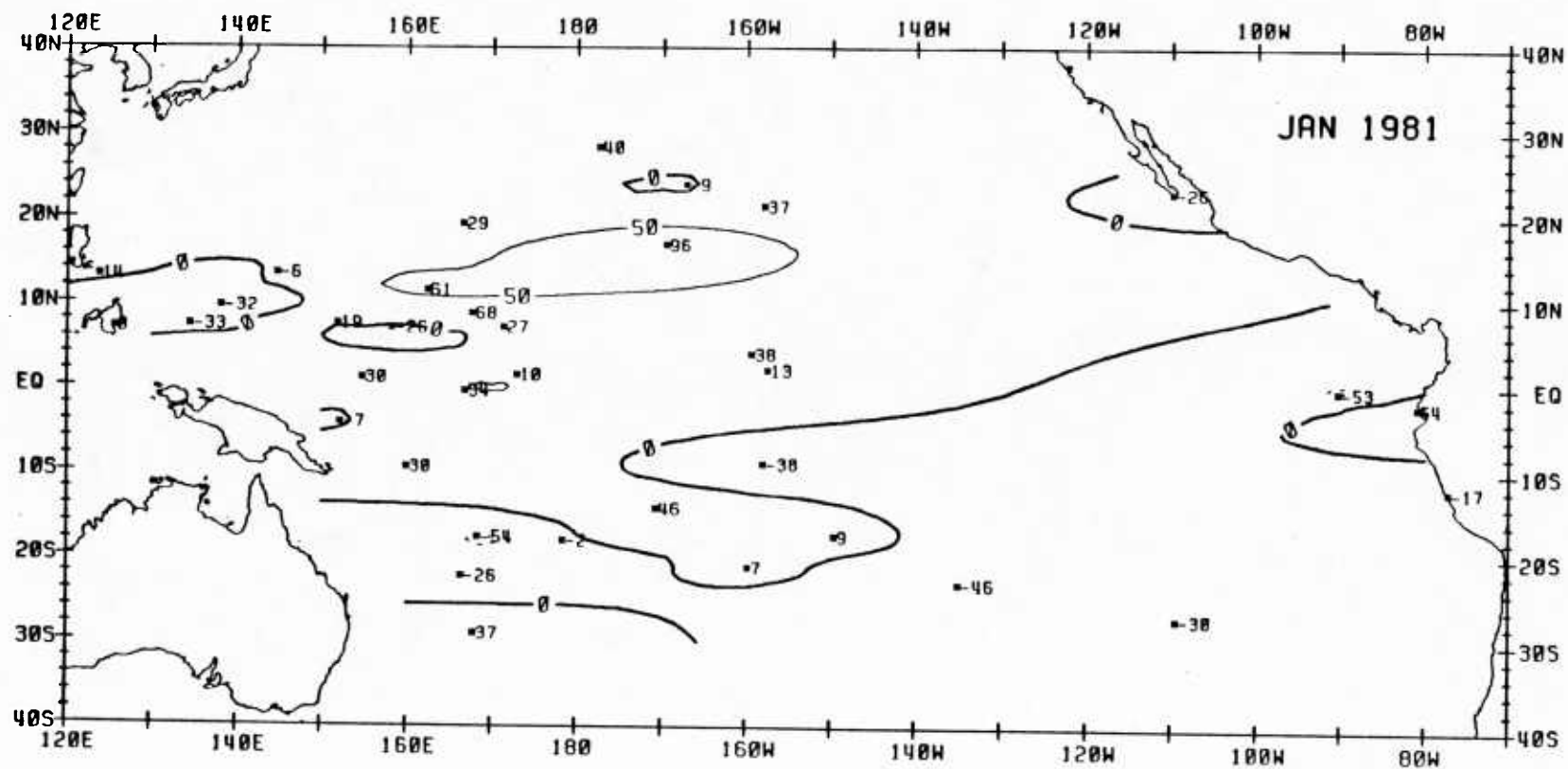


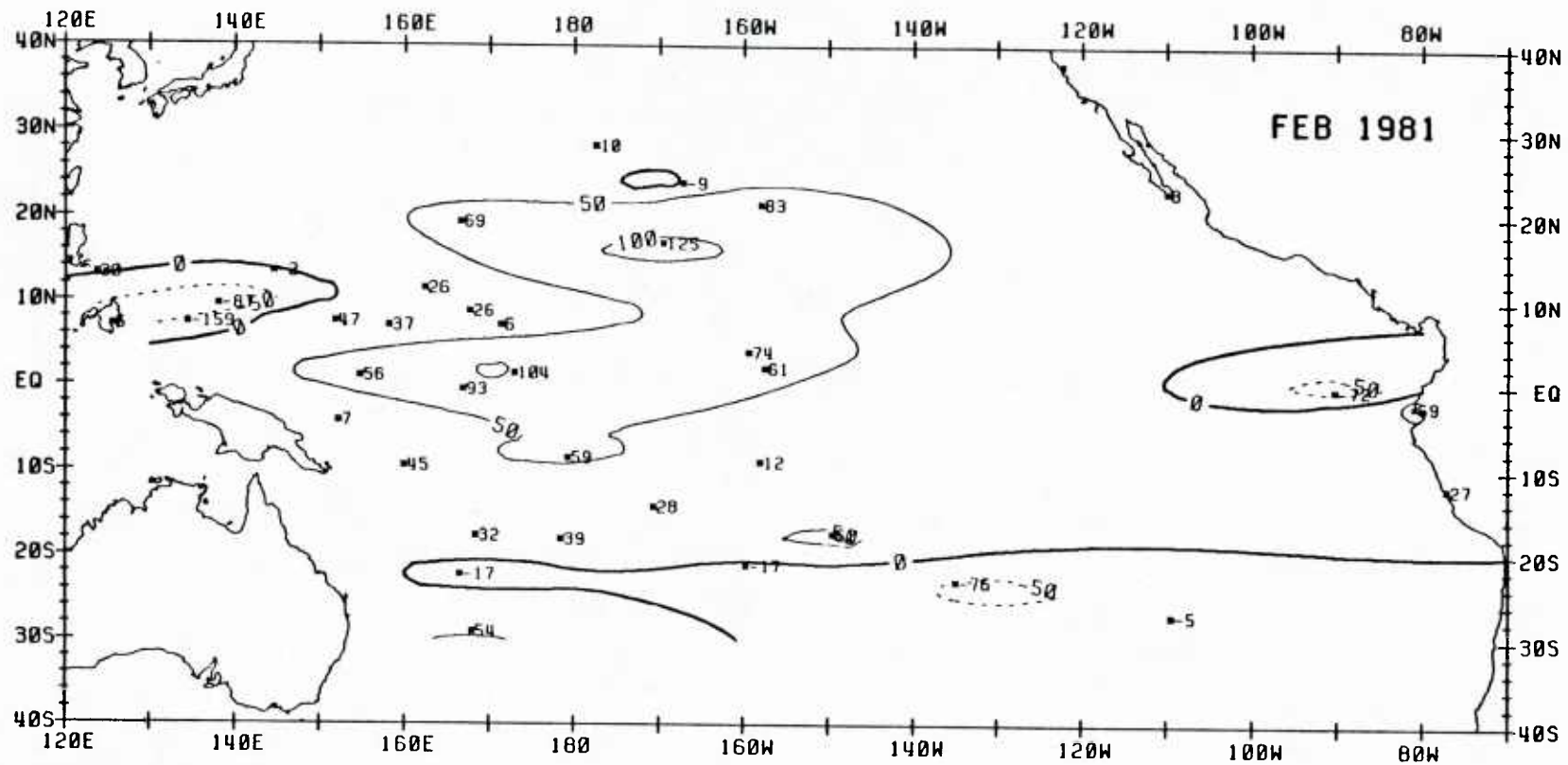


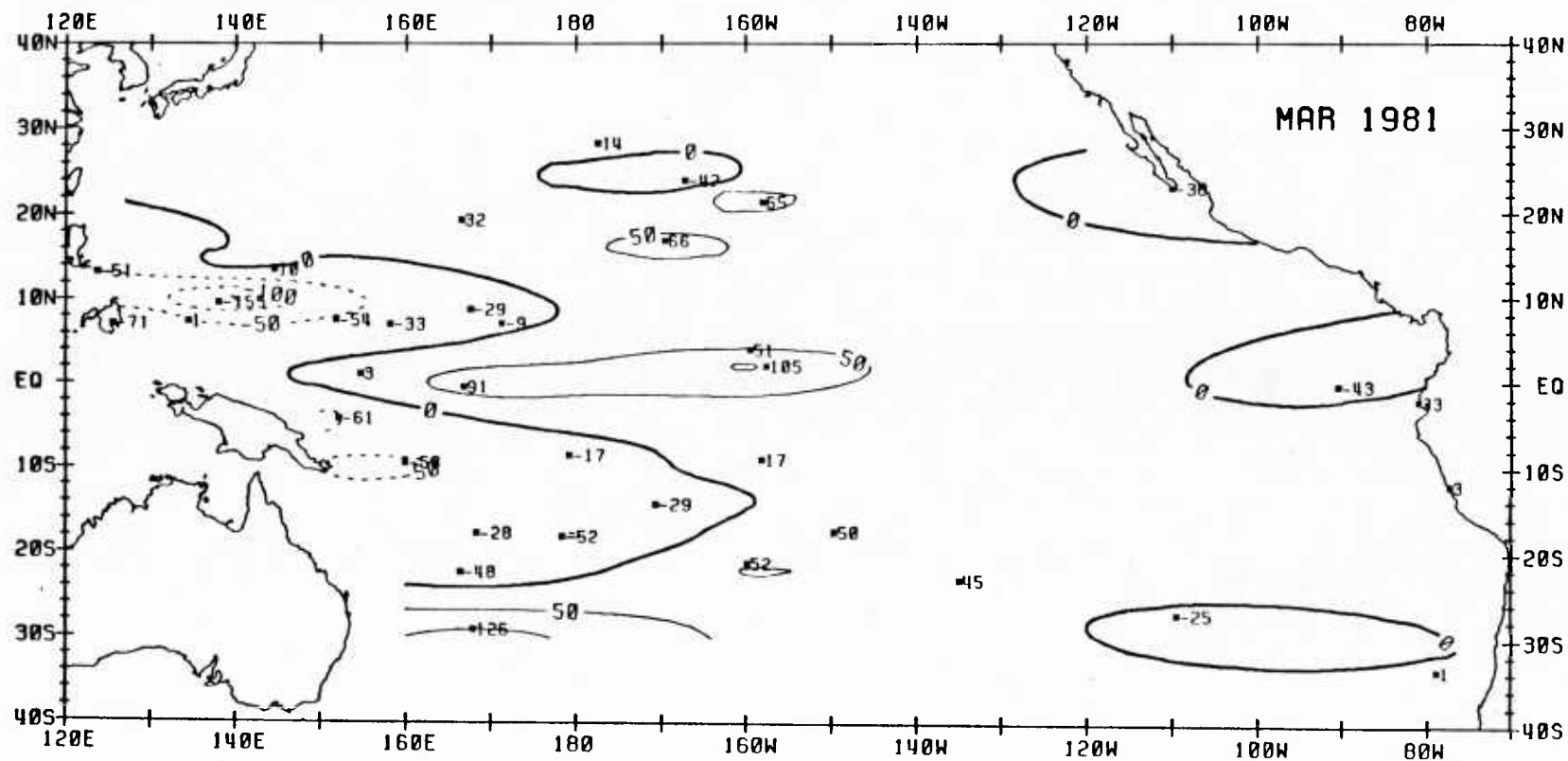


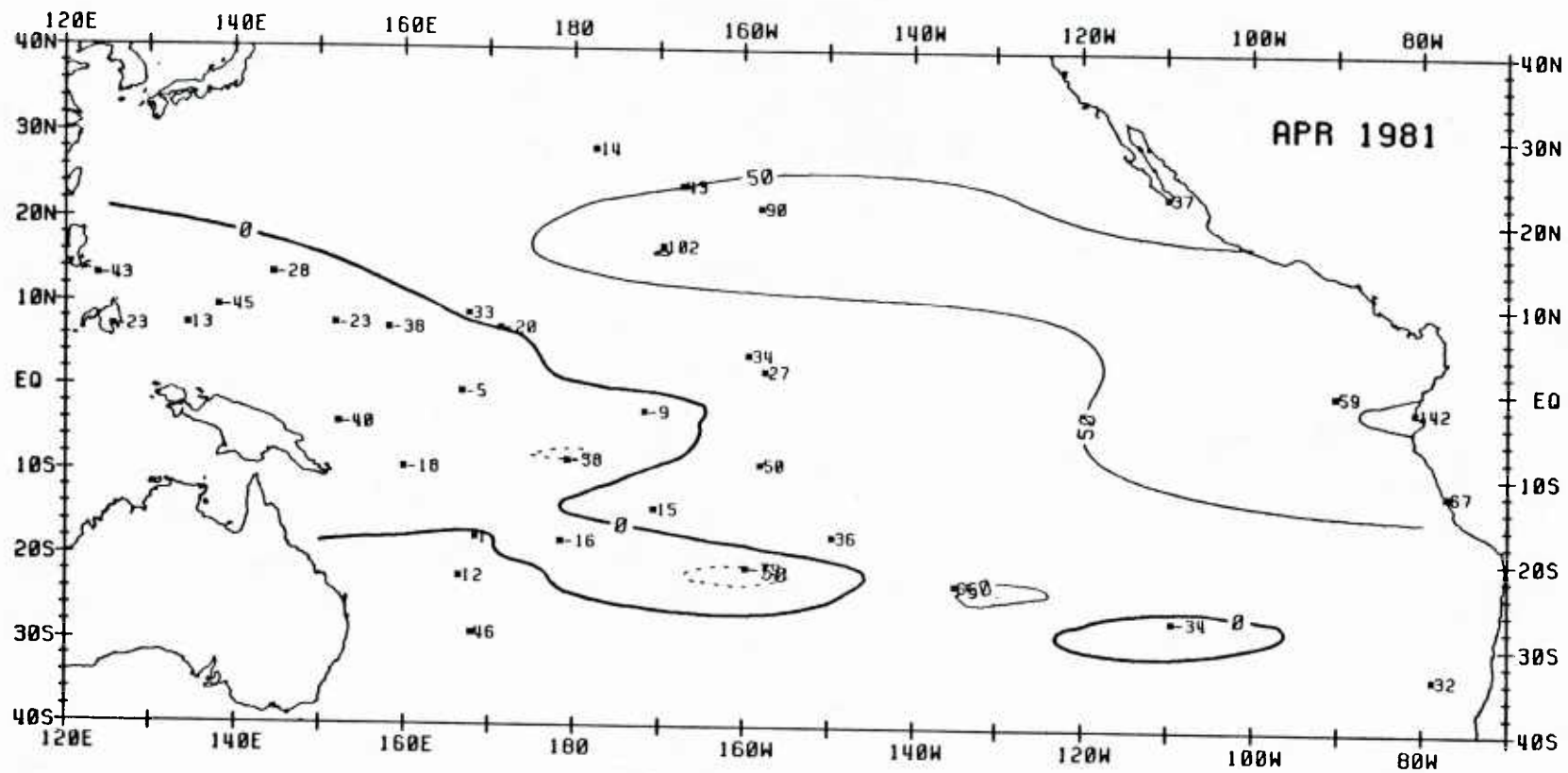


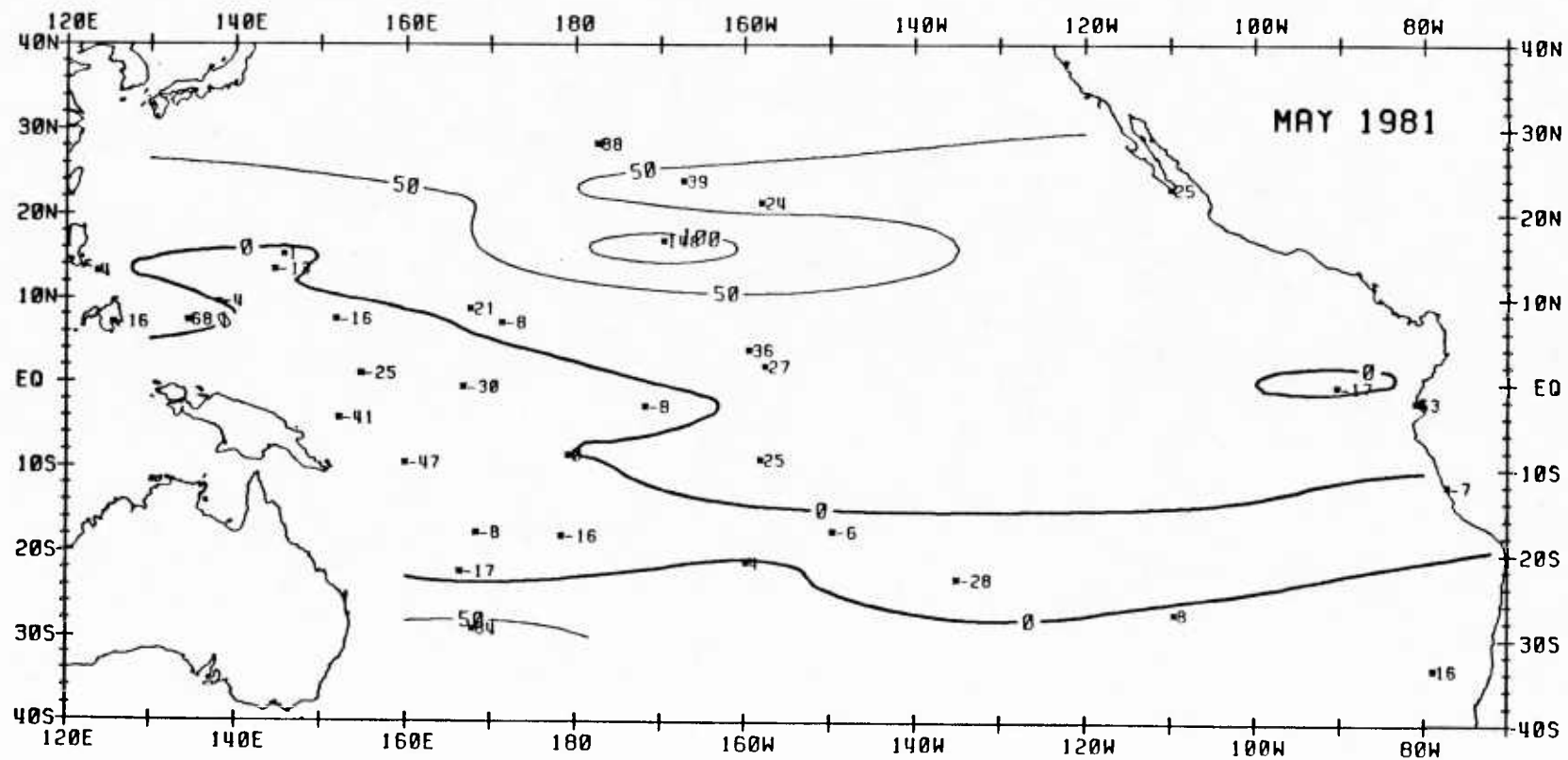


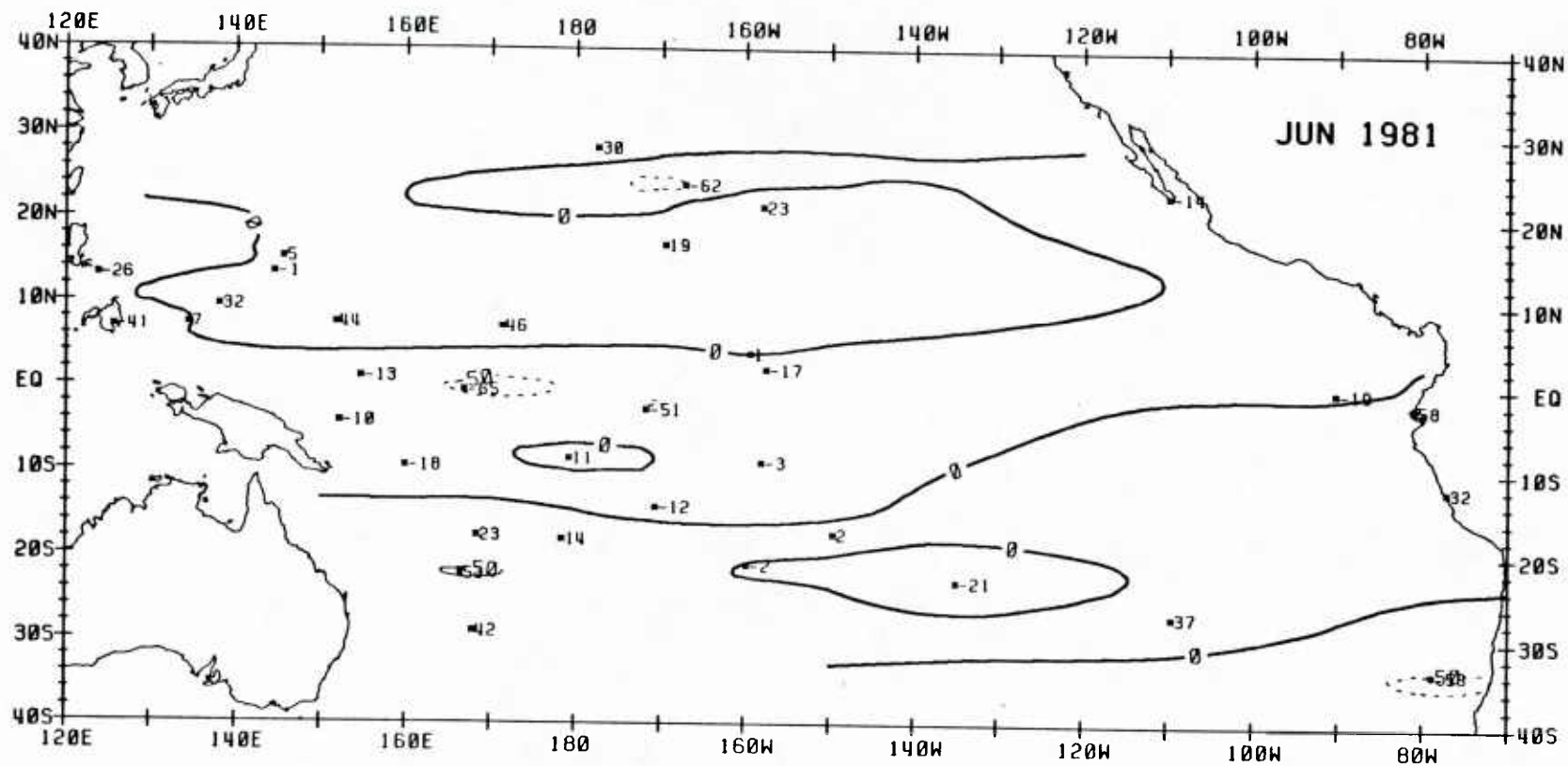


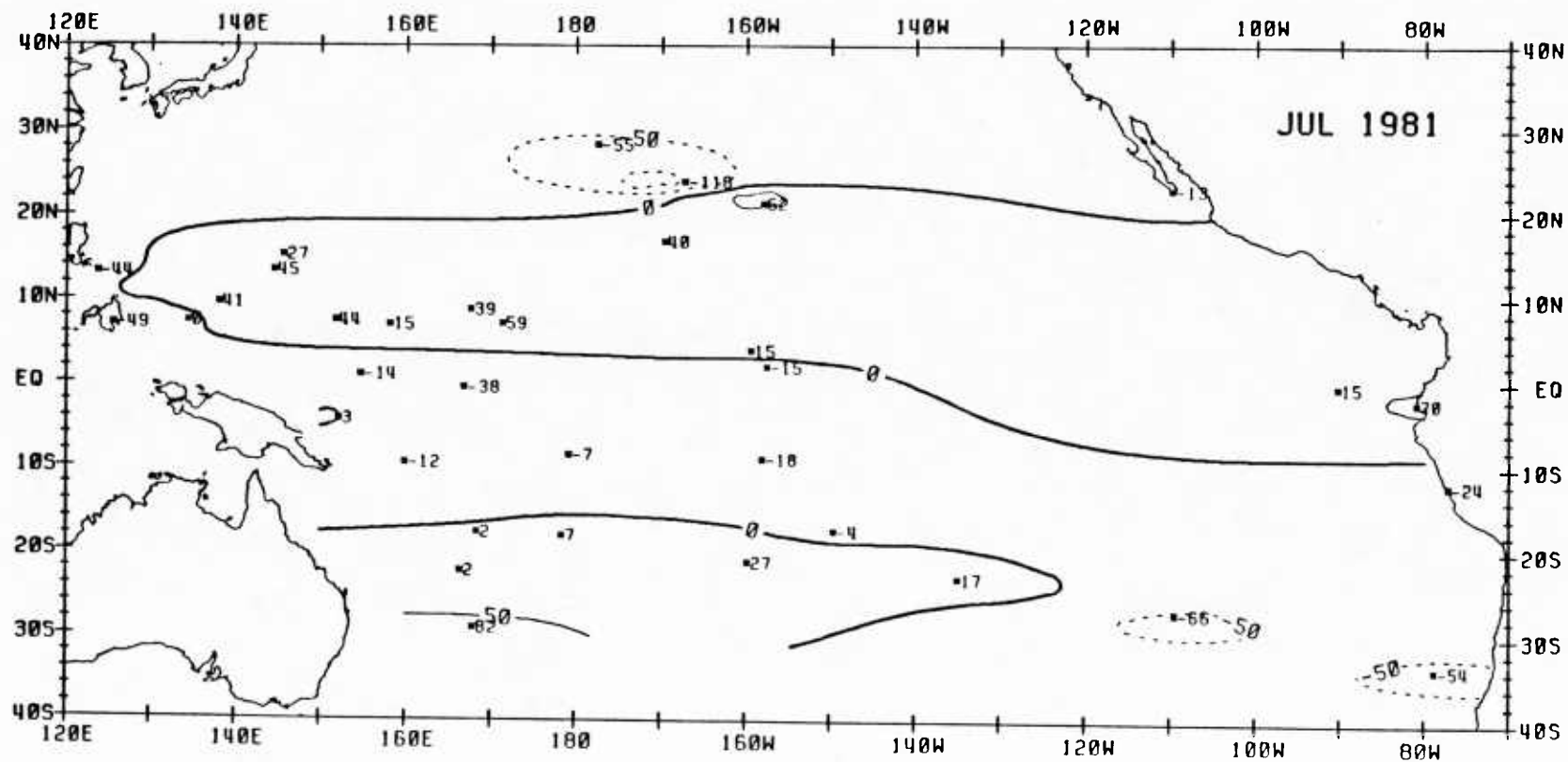


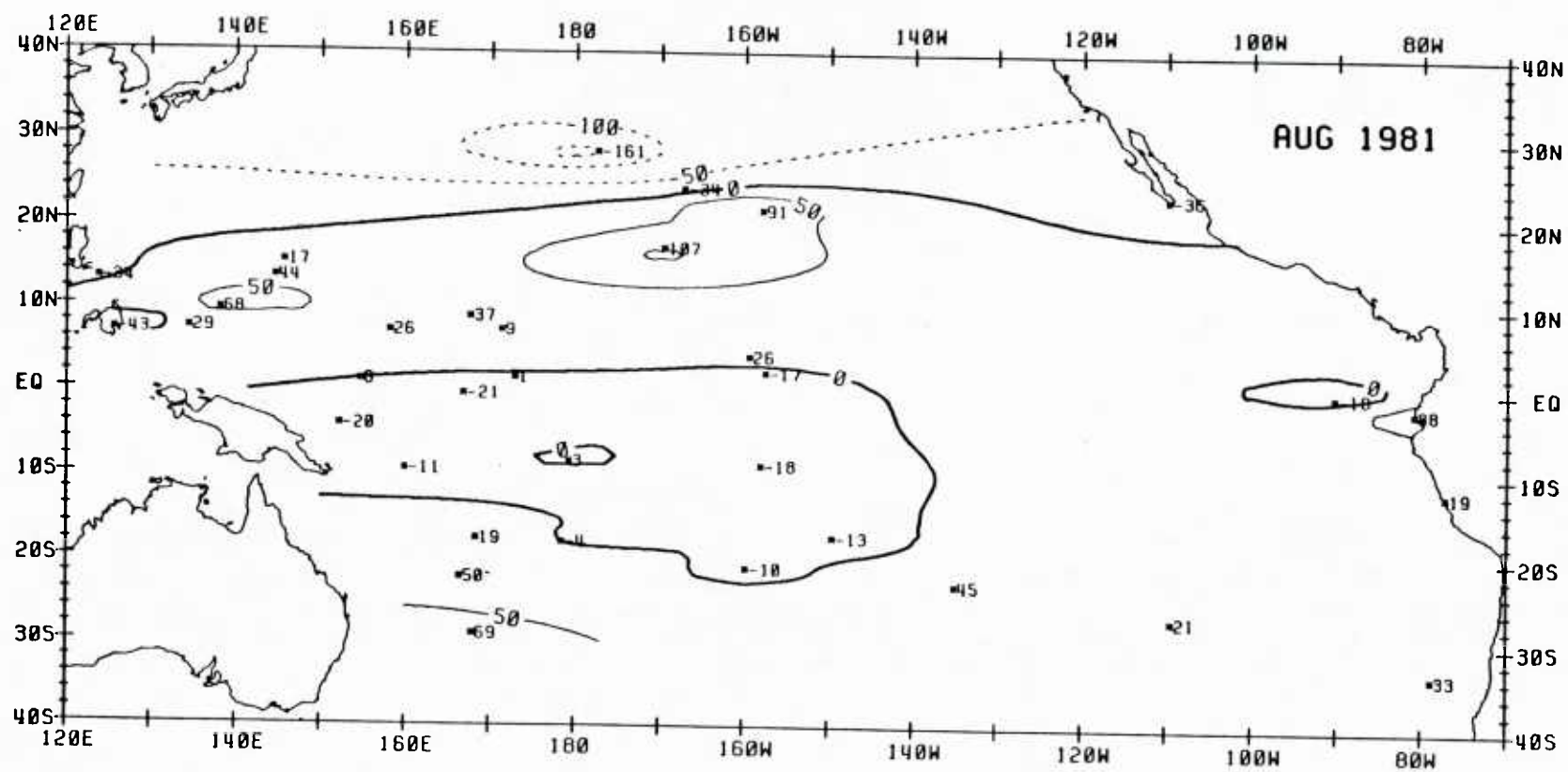


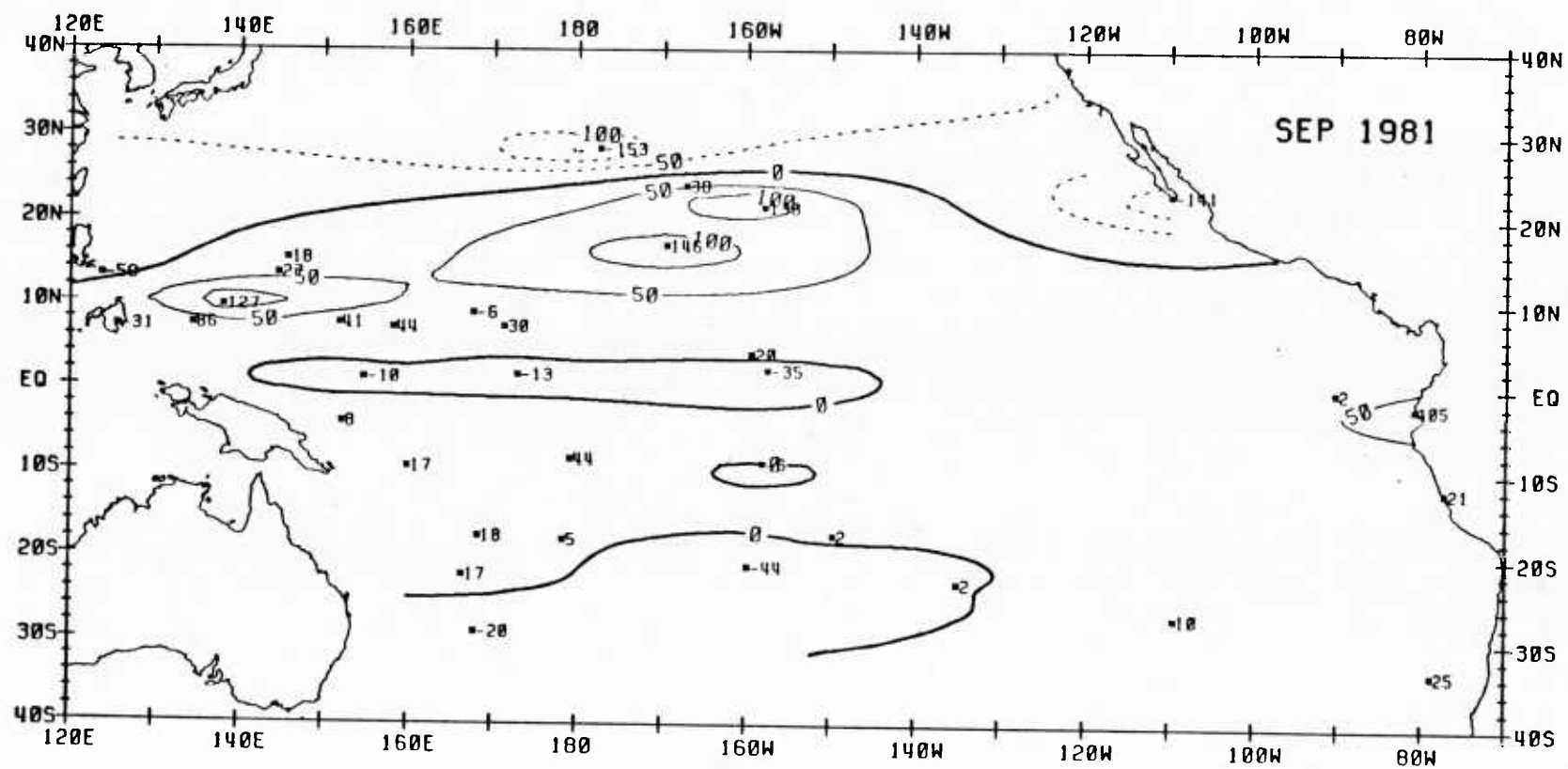


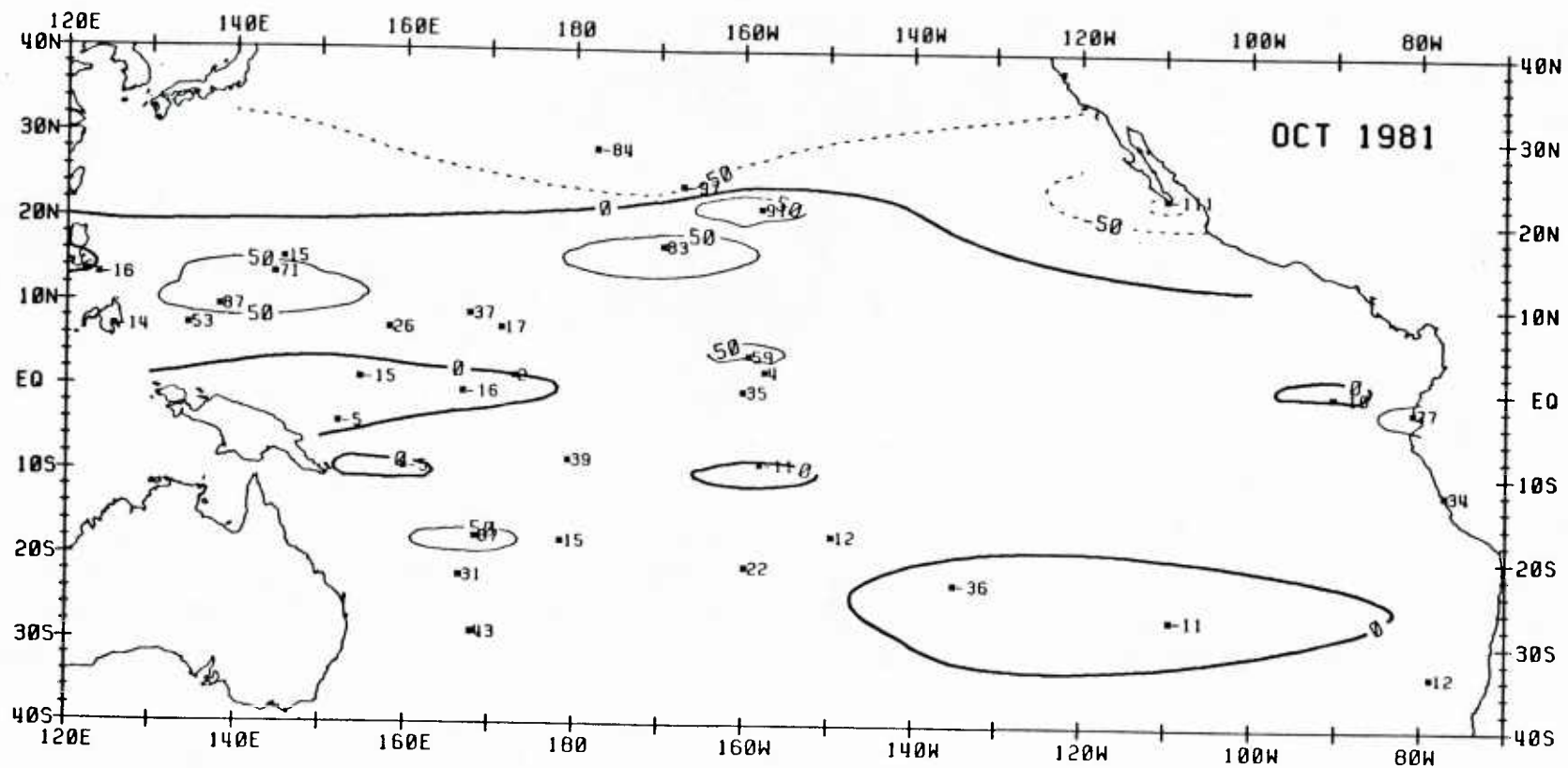


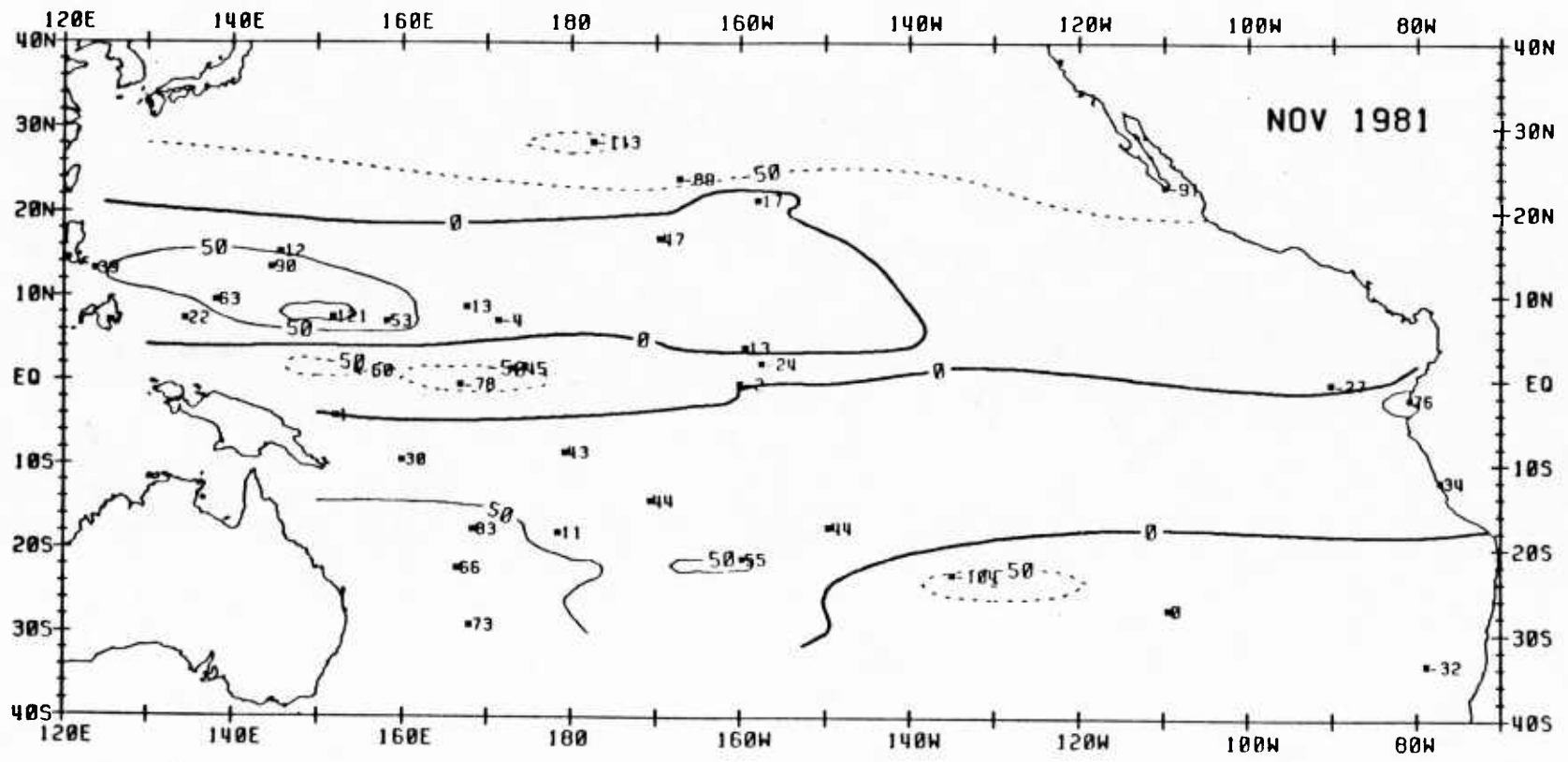


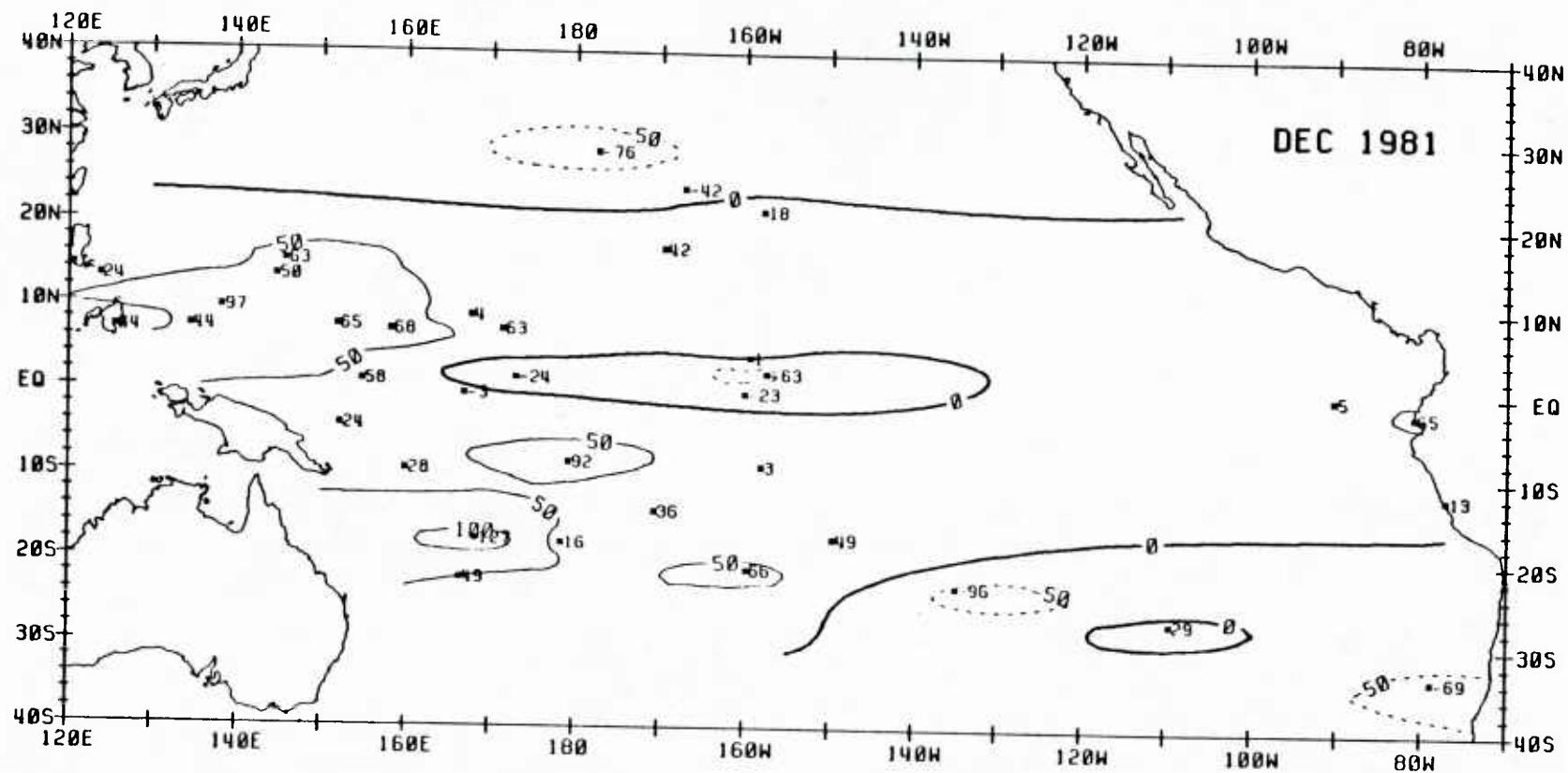












U215426